"I would have everie man write what he knowes and no more."—MONTAIGNE

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EDITORIAL

IT would be interesting to know how many readers digest the editorial before the rest of the Journal. An editorial, unlike its sister annotation, makes room for unfettered discourse on the contents of the Journal, but the writer of the annotation has to limit his thoughts within certain boundaries. Both kinds of article should have a place in our Journal because some thoughts are better if they are organized and others are better for the lack of restraint. For some the editorial may be the only part of the Journal that can be understood at a single reading.

This Journal attempts to please all its readers, for there is space for papers on clinical and on other aspects of anaesthesia. It should not be thought that what goes under the heading of "clinical" is not scientific, nor that what appears under "original" is not for the clinician. There is only one truth, irrespective of whether the research is on human beings or inert substances.

The widespread use of muscle relaxant drugs during surgical operations has led the anaesthetist to consider what the inevitable changes in respiration mean: he tends to forget that the patient's respiration was subject to considerable change even in the heydays of ether and chloroform.

The problems associated with carbon dioxide have received much attention from anaesthetists on both sides of the Atlantic ocean. In an American panel discussion on pulmonary ventilation the needs for monitoring by instruments was brought out because of the difficulty of judging respiratory exchange from visual impressions. Most of the instruments are at present unobtainable for the practical anaesthetist, and he would need technical assistance to maintain them in running order.

In this issue three writers have produced papers dealing with the analysis of carbon dioxide by simple methods. Dr. Lund and his colleagues' investigation of the efficiency of soda lime in a closed circuit deals with how it works in man and not in models. Models can be controlled but they do not tell the whole story and we are interested in man.

Dr. Brewin and his colleagues are to be congratulated on their discovery of the metabolic acidosis occurring during the rewarming process after hypothermia. Clearly this is the starting point of investigations of fundamental importance to the thoracic surgeon and anaesthetist.

Every patient under anaesthesia has to breathe during surgical operations, or have artificial respiration performed upon him, and each state raises problems which are not lessened because the patient breathes from an artificial atmosphere, supplied to him from a confined space—the apparatus, and this exists in many different forms.

It is to be hoped that this collection of papers will stimulate more work so that a further symposium on the same subject will in due course arise.

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ACID-BASE EQUILIBRIUM IN HYPOTHERMIA

BY

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ACID-BASE equilibrium during hypothermia has received much attention lately. Few of the studies so far made, however, have borne much relevance to the problems of the cardiac surgeon who uses hypothermia combined with circulatory arrest to allow him sufficient time for intracardiac surgery. It would be strange if a period of ten minutes circulatory arrest did not appreciably modify the physicochemical changes revealed when an animal is merely cooled. Moreover, the surgeon justifiably requires information about the end-product, i.e. the rewarmed patient who returns to the ward.

Our experiments were devised to give information:

(1) On the state of acid-base balance shown by blood when equilibrated *in vitro* at 26°C compared with that revealed after similar equilibration at 37°C.

(2) On the changes of acid-base balance which occur when animals are cooled to 26°C and are rewarmed to 37°C with or without operative interference. The results obtained on 26 dogs subjected to cooling, thoracotomy and circulatory arrest followed by rewarming have been compared with those obtained from 7 patients during and following intracardiac operation under hypothermia.

Our results have recently been presented *in extenso* elsewhere (Brewin, Gould, Nashat and Neil, 1955).

Theoretical considerations.

The ionic constituents of blood are the cations, the charge of which is invariant over the biological range of pH, and the anions. The anionic component comprises: (*a*) "fixed anions" (mainly Cl') whose total charge is likewise invariant over the biological range of pH; (*b*) "buffer anions" (HCO_3', Hb' and Pr') whose state of charge depends on the pH.

The cationic concentration is about 150 m.eq/l. in normal human blood; this is equalled by the total anionic concentration. Of the 150 m.eq/l. total anionic concentration about 100 m.eq/l. are in the form of fixed anions, the remaining 50 m.eq/l. being buffer anions. Singer and Hastings (1948) have introduced the term "buffer base" to describe the cationic concentration electrically equivalent to that of the buffer anions. Buffer base concentration or Bb^+ therefore equals 50 m.eq/l. of cation in normal

human blood. As the fixed cationic and fixed anionic concentrations remain invariant for a given blood over the biological range of pH produced by increasing the carbon dioxide tension to which such blood is exposed, it therefore follows that the total buffer anionic concentration and hence Bb^+ remains constant. However, although the total buffer anionic concentration remains the same, there is a change in the parcellation of buffer anions. It can be shown that normal human blood equilibrated at a carbon dioxide tension of about 170 mm Hg, has a pH of 7.00, and a bicarbonate ion concentration of 35 m.eq/l. The haemoglobin and plasma protein ionic concentrations together equal 15 m.eq/l. The total buffer anionic concentration thus equals 50 m.eq/l. At 15 mm Hg carbon dioxide tension the same blood shows a pH of 7.70, a bicarbonate ion concentration of 15 m.eq/l. and a combined haemoglobin and plasma protein ionic concentration of 35 m.eq/l. Thus the uptake of carbon dioxide as bicarbonate is achieved by the simultaneous suppression of haemoglobin ionization and, to a lesser extent, that of the plasma proteins. The formation of bicarbonate ion is indeed limited by the supply of potential hydrogen acceptors such as the histidine ions in the haemoglobin molecule; for each HCO_3' formed one H^+ must be released—when this associates with the haemoglobin ion one protein anionic group is consequently withdrawn.

The ionization of the strong electrolytes is scarcely affected by temperature. Hence the fixed anionic component and the total cationic component remain the same when the temperature of equilibration of the blood is lowered. It therefore follows that the buffer anion concentration is not affected in these conditions and hence the Bb^+ remains unaltered. Nevertheless the distribution of the buffer anions is altered owing to the reduced ionization of haemoglobin and the plasma proteins at lower temperatures (Warburg, 1922; Stadie and Martin, 1924; Martin and Lepper, 1926; Adair, Cordero and Shen, 1929; Brewin, Nashat and Neil, 1955; Nashat, Neil, Samueloff, 1955). As less proteinic ions are formed, more bicarbonate ions take their place and thus the carrying power of the blood for carbon dioxide is increased. This increased CO_2 carriage by blood at low temperatures has to be considered in applications of the Henderson-Hasselbach equation:

$$pH = pK' + \text{Log}\{[HCO'_3]/[H_2CO_3]\}$$

In this equation all the factors on the right-hand side are altered by the temperature of equilibration of the blood. For a given pCO_2, $BHCO_3$ is increased at lower temperatures. H_2CO_3 is derived by multiplying the partial pressure of CO_2 by a solubility factor; this solubility factor is increased with falling temperature. At pCO_2 of 40 mm Hg, $H_2CO_3 = 40 \times 0.0313$ mM/l. = 1.252mM/l. at 37°C. At 26°C at the same carbon dioxide tension the solubility factor has increased from 0.0313 to 0.0411; hence the $H_2CO_3 = 40 \times 0.0411 = 1.644$mM/l.

pK′ which is the negative logarithm of the apparent first dissociation constant of carbonic acid is 6.11 at 37°C and shows a temperature variation (dK′/dT) of −0.005. Hence at 26°C pK′ = 6.165. One is therefore confronted by an extremely complicated series of changes.

These may be resolved by studying the actual behaviour of blood equilibrated *in vitro* with various carbon dioxide tensions at 37°C and 26°C.

Experiments in vitro.

A series of tonometers were filled with 5 ml blood samples and CO_2/air mixtures. Equilibration of the blood in the tonometers was allowed by rotation in a thermostatically controlled water bath for twenty minutes, thereupon the total CO_2 content of the blood was determined with the Van Slyke manometric apparatus. The total pressure in the tonometer was measured in each case, and a sample of the gas phase was analysed in a 21-ml Haldane apparatus. The carbon dioxide tension in each tonometer was thereby calculated. The pH of each blood sample was measured by a Stadie glass electrode system, the electrode being surrounded by a water bath, thermostatically controlled at 37°C. Two graphs were constructed from the results: (1) total CO_2 content was plotted against the CO_2 tension, using logarithmic scales (Peters, 1923); (2) the CO_2 tension was plotted on a logarithmic scale against pH (Brewin, Nashat and Neil, 1955).

The procedure was repeated using a temperature of 26°C for the equilibrations. The pH measurements were made at 26°C. The results are shown in figure 1 (A, B). Figure 1A shows the increase in carbon dioxide carrying power which blood displays after equilibration at 26°C compared with that after equilibration at 37°C. Figure 1B shows that the log pCO_2/pH plot is linear and is unaffected by the temperature of equilibration. These results were found to hold for the blood

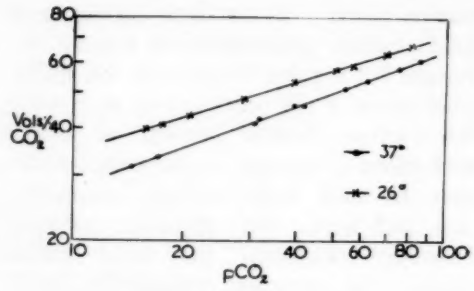


FIG. 1A

Dissociation lines of human blood at 37°C and 26°C. The CO_2 content (vol. per cent) is plotted against the CO_2 tension each on a logarithmic scale. Note that the carrying power of the blood for CO_2 is increased at the lower temperature.

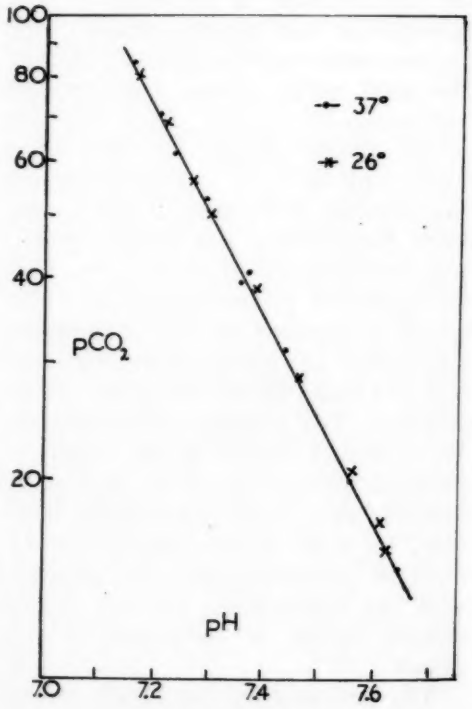


FIG. 1B

Log pCO_2/pH graph of human blood. The points obtained by equilibration at 37°C lie on the same line as those obtained by equilibration at 26°C.

of men, dogs and oxen. Nashat and Neil (unpublished) have recently shown that the log pCO_2/pH plot for any given blood is identical at temperatures of equilibration between 10°C and 40°C, provided that the pH measurements be made at the same temperature as that of the corresponding equilibration.

The log pCO_2/pH plot provides a convenient method of assessing the development of a fixed acidosis. If lactic acid enters the blood of an animal *in vivo* the fixed anion lactate "requires" cation for its electrical neutralization. This cation is drawn from the buffer base component and Bb^- is correspondingly reduced. The log pCO_2/pH plot is displaced to the left of that of the normal blood. Hence if blood be removed from an animal cooled to 26°C and after equilibration shows a log pCO_2/pH plot to the left of that derived from equilibrations of blood removed from the same animal before cooling began, then the blood withdrawn in the hypothermic state shows a fixed metabolic acidosis.

Figure 2 shows the log pCO_2/pH plots of human blood with varying concentrations of Bb^-. Bb^- was adjusted to 35 mM/l. by addition of lactic acid and to 65 mM/l. by addition of bicarbonate. Equilibrations were done at 37°C and 26°C and it will be noted that the log pCO_2/pH graph for any blood of known Bb^- is almost the same at 37°C as at 26°C, there being only slight discrepancy in the case of the blood with $Bb^- = 35$ mM/l. The slope of the log pCO_2/pH graph was found to vary with the haemoglobin concentration of the blood. The alterations so produced slightly modify the above conclusions. The paper of Brewin, Gould, Nashat and Neil (1955) should be consulted for full details.

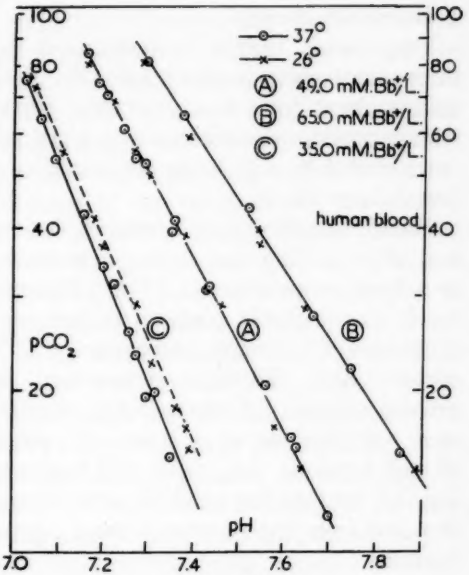


FIG. 2

Log. pCO_2/pH graphs of human blood. The buffer base content of the blood, normally 49.0 mM/l. was altered to 65.0 mM/l. by suitable addition of sodium bicarbonate, and to 35.0 mM/l. by addition of lactic acid.

Note that the points obtained by equilibration at 37°C and 26°C are unaffected by temperature in the case of blood with a normal or raised buffer base content. In the case of blood with a lowered buffer base content there is a slight discrepancy.

The coincidence of the log pCO_2/pH plots derived from equilibration of a given blood at different temperatures dispels the notion that a gaseous acidosis occurs in hypothermic conditions due to the altered solubility of carbon dioxide *per se*. The effect of increased H_2CO_3 formation due to the greater solubility of CO_2 is offset by the increased bicarbonate carriage at the lower temperature.

We have made considerable use of the equilibration technique in experiments *in vivo*.

Experiments in vivo.

Dogs were lightly anaesthetized by thiopentone given intravenously. A cuffed endotracheal tube was inserted. Blood stream cooling was effected by a glass coil (surrounded by ice) being connected as a femoral a-v shunt.

Blood samples were removed before and after cooling and during rewarming to a final temperature of 37°C. Haematocrit, haemoglobin content, lactate concentration, O_2 content and capacity, CO_2 content and pH were determined on arterial samples. Corresponding aliquots were equilibrated at a series of carbon dioxide tensions. Log pCO_2/pH lines and log CO_2 content/log pCO_2 lines were constructed from the results of these equilibrations.

These procedures were carried out in dogs cooled and rewarmed without operative interference, breathing spontaneously or artificially ventilated. An additional series of experiments was performed on dogs subjected to thoracotomy and circulatory arrest during hypothermia. In all cases the animals were allowed to rewarm to 37°C.

(a) *Animals breathing spontaneously.* A full account is given elsewhere (Brewin *et al.*, 1955). Some degree of fixed acidosis was invariably found during the course of these experiments. The final picture after the dogs had rewarmed to 37°C was one of mild metabolic acidosis with a loss of CO_2 combining power of 2–5 mM/l. and with lactate concentrations 1.5–4 mM/l. above the precooling values. The claims of Cranston, Pepper and Ross (1955) that no metabolic acidosis occurs in hypothermic dogs breathing spontaneously were refuted by Brewin *et al.*

(b) *Animals under pump ventilation.* Pump ventilation was maintained during cooling and subsequent rewarming to 28–29°C whereupon the animals were allowed to breathe spontaneously during the rest of the rewarming period. Figure 3 shows the composite results of these experiments presented in the form of a log pCO_2/pH graph. All points on the graph are obtained by equilibration of blood samples withdrawn during the

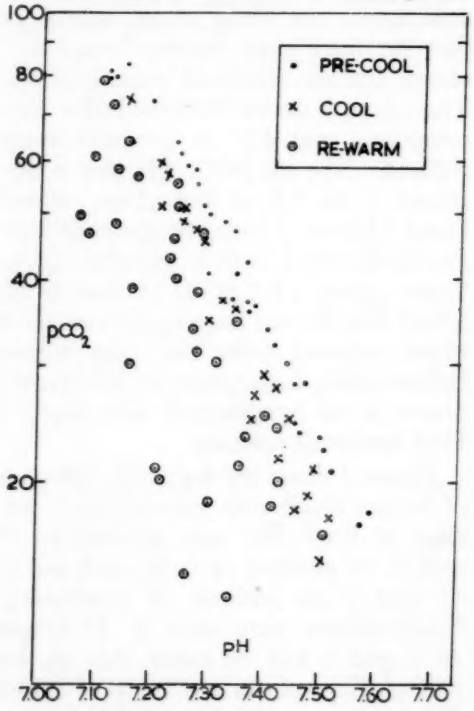


FIG. 3

Composite results from ten experiments in which dogs were cooled to 26°C and then rewarmed. Pump ventilation was maintained throughout cooling and during rewarming until a body temperature of *c.*29°C was attained. Thereafter the dogs breathed spontaneously.

The points obtained by equilibrations at the temperature of withdrawal of the various blood samples are plotted on a log pCO_2/pH graph. Note that the points obtained after rewarming lie to the acid side of those obtained by equilibration of blood removed before cooling began.

course of these experiments on ten dogs. In eight of the dogs the final picture was one of moderately severe metabolic acidosis. The remaining two dogs showed a considerable degree of metabolic acidosis. The points plotted on the far left of the graph show the results of equilibrations in these two animals.

(c) *Animals subjected to thoracotomy and circulatory arrest.* During cooling the chest was opened and loose ligatures were placed round the venae cavae and vena azygos. After cooling to a steady rectal temperature of 26°C the venous return was arrested for ten minutes. After restoring the venous return a period of three to five minutes was allowed for circulatory readjustments before a blood sample was removed (" postclamp sample ") for the requisite determinations and equilibrations. The chest was closed and the animal was allowed to rewarm to 37°C. The composite results of experiments on 26 dogs are shown in figure 4 (A, B). This figure leaves no doubt that a severe degree of metabolic acidosis remains on completion of rewarming (Brewin and Neil, 1955). Lactate estimations showed a progressive rise during the course of the experiments, sometimes reaching a final concentration of 10 or more m.eq/l.

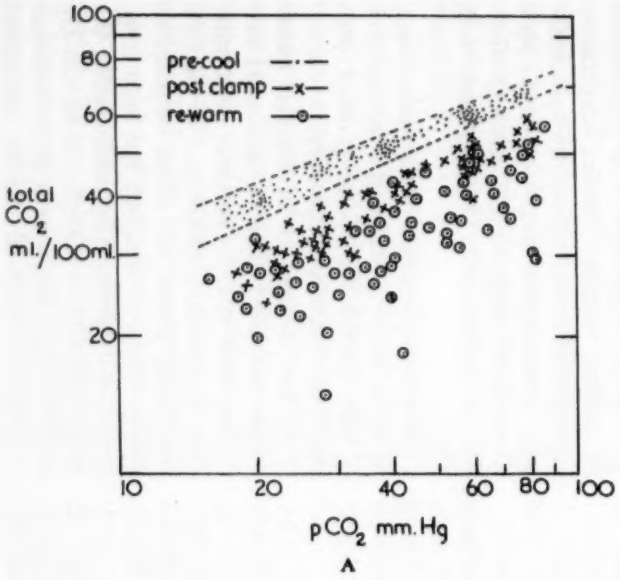
These experiments were devised to copy the conditions experienced by the patient undergoing cardiac operation during hypothermia. Similar investigations were carried out in seven such patients thanks to the co-operation of Sir Russell Brock. The results of these studies were in every way similar to those obtained in dogs. It was not uncommon to find the CO_2 combining power of blood removed at the completion of rewarming was 7–10 mM/l. below normal. Lactate concentrations were 7–8 mM/l. above normal values.

We feel that the rising lactate concentration found in blood removed at intervals during rewarming is due to a combination of two factors: (1) some degree of circulatory insufficiency following arrest of venous return; (2) an impaired ability of the liver and other organs to metabolize lactate.

With respect to the first factor, it is known that the cardiac output of an animal kept on the operating table for many hours falls away progressively, even though little operative interference be made. The additional insult of thoracotomy and ten minutes circulatory arrest followed by labouring against the high viscosity of the blood (due to the lowered temperature and to haemoconcentration) will further contribute to an impairment of cardiac output. Reflex circulatory adjustments brought about by baroceptor and chemoceptor activity have been shown to be sluggish and scarcely effective in hypothermia (Nashat and Neil, 1955).

Whatever the cause of the lactacidosis, however, its presence in an acute survivor of this formidable operation must prejudice his chances of recovery.

Ad hoc therapy of intravenous bicarbonate administration was instituted first in dogs and later in patients rewarming after intracardiac operation. If the CO_2 combining power of blood withdrawn (after closure of the chest has been completed) is determined by equilibrating the blood with CO_2 at a tension of 40 mm Hg at 37°C then the amount of intravenous bicarbonate required can be calculated



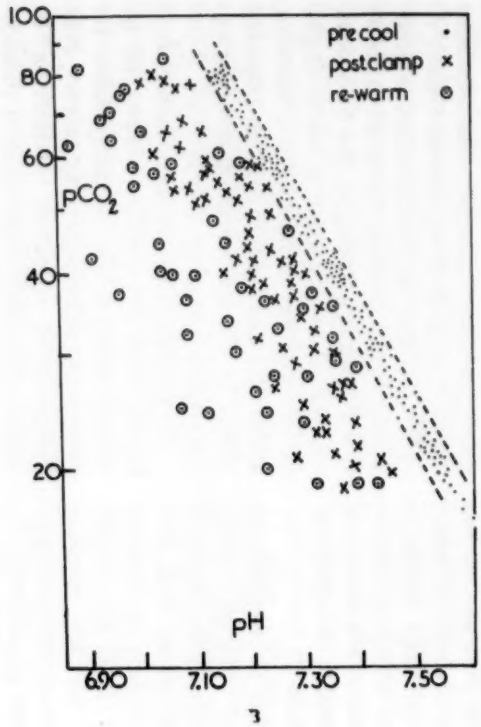


FIG. 4

Shows composite results of 26 experiments on dogs cooled, subjected to 9–10 minutes circulatory arrest and rewarmed to 37–38°C. All animals were cooled to a body temperature of about 26°C.

Equilibration of all blood samples was performed at 26°C.

(A) Log CO_2 dissociation graph.

(B) Log pCO_2/pH graph.

Both graphs show that fixed acidosis evident in the postclamp samples becomes more severe as rewarming is completed.

In each graph the broken lines show the limits of the "precooling" points.

by a formula similar to that of Hartmann and Senn (1932):

$$mM = \frac{(60 - CO_2) \times 0.7W}{2.24}$$

where mM = mM of $NaHCO_3$ required by intravenous administration.

CO_2 = true plasma CO_2 content (ml/100 ml).

W = body weight in kg.

This proved entirely successful in restoring a normal picture of acid-base equilibrium.

Of greater importance, however, is to determine how effective steps may be taken to prevent the development of the acidosis. We have found that depression of liver function results from cooling and circulatory arrest followed by rewarming. Galactose tolerance tests during the course of these experiments have revealed that cooling alone without operative interference causes a depression of liver function revealed by a delay in the removal of galactose from the blood. However, in such cases on rewarming, liver function is restored, as revealed by an 80 per cent recovery of the rate of clearance of galactose from the blood. When cooling is accompanied by circulatory arrest the galactose clearance following rewarming shows negligible improvement on that seen immediately after cooling (fig. 5). Functional studies of this type showed a good correlation with those of histological examinations of liver removed from animals after rewarming. In animals merely cooled and rewarmed sections of liver appeared normal. Livers removed after the completion of rewarming in animals which had suffered circulatory arrest during hypothermia showed, on sectioning, gross centrolobular congestion, haemorrhage and necrosis.

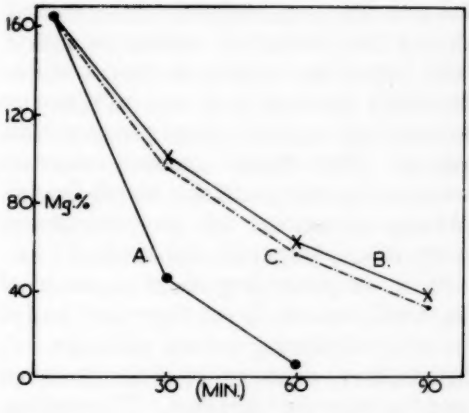


FIG. 5

Galactose clearance curves. Galactose concentration in milligrams per cent (ordinate) is plotted against time in minutes after the injection of 0.4 g/kg body weight of galactose (abscissa).

Tolerance tests were performed before and after cooling thoracotomy and ten minutes circulatory arrest and following rewarming to 37°C.

Line "A" shows the clearance of galactose before cooling began.

Line "B" shows the rate of clearance of galactose after cooling thoracotomy and circulatory arrest.

Line "C" shows the rate of clearance of galactose on completion of rewarming.

Note that line "C" shows a negligible improvement in the rate of galactose clearance compared with that at 26°C.

Measurement of the pressure in the inferior vena cava in hypothermic animals during ten minutes circulatory arrest showed that the central venous pressure rose 15–20 cm H_2O. Hence the liver is subjected to considerable congestion accompanied by complete anoxia during this period. Subsequent work was carried out in order to perfect a method of "decongestion" of the liver. Two techniques were devised:

(1) Blood was aspirated from the inferior vena cava via a catheter (whose tip

lay adjacent to the hepatic venous orifice) during the period of venous occlusion. The blood was aspirated into a sterile siliconed reservoir at a rate sufficient to prevent the central venous pressure from rising. The blood removed was re-admitted to the circulation by gravity following restoration of the circulation. Surprisingly large volumes of blood (300–400 ml—representing about one-third of the blood volume of the dogs used) had to be removed during venous occlusion. A satisfactory recovery of liver structure and function was obtained. The residual acidosis after completion of rewarming was correspondingly less severe. However, the method was discarded for practical reasons. The danger of extravascular coagulation is the most obvious of these. It is unwise to add heparin to the blood stored extravascularly as the re-introduction of this heparinized blood caused great trouble with subsequent oozing of the chest wound surfaces.

(2) Blood was aspirated from the inferior vena cava during venous occlusion period by a Jouvelet pump which then forced it into the arterial tree. In the earlier experiments of this type, aspiration by the Jouvelet pump was allowed from the inferior vena cava only. The central venous pressure in the inferior vena cava was thus reduced to very low levels. However, the pressure in the superior vena cava correspondingly rose to levels which were higher even than those which occurred when venous occlusion alone was practised. In later investigations alternate aspiration from the inferior and superior venae cavae was practised. The functional results of these two latter procedures were similar.

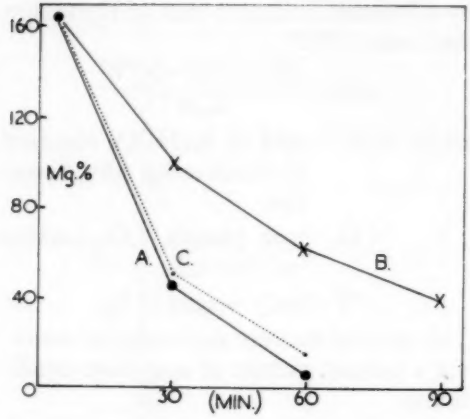


FIG. 6

Galactose clearance curves before and after cooling thoracotomy and ten minutes circulatory arrest, followed by rewarming to 37°C. During circulatory arrest central venous pressure was prevented from rising by aspiration of blood from the inferior vena cava by a Jouvelet pump which in turn forced the blood into the arterial tree.

Line "A" shows galactose clearance rate before cooling.

Line "B" shows the rate of galactose clearance after cooling and circulatory arrest.

Line "C" shows the rate of galactose clearance after rewarming.

Note that the rate of galactose clearance returns after rewarming almost to the precooling value.

Galactose clearance returned almost to its precooling value after rewarming (Fig. 6). Histological examination of the liver revealed a picture indistinguishable from that of the normal. The residual metabolic acidosis was of a relatively trivial degree.

Alleviation of venous congestion of the liver during the period of total circulatory arrest ensures a subsequent recovery of hepatic function on rewarming which is almost complete. The marked improvement in hepatic function produced by "decongestion" seems to be correlated with an improvement in the final picture shown by the acid-base balance of the blood. Presumably lactate and other acid

metabolic products are more completely removed by liver cells which have been protected from the depressant effect of congestion and anoxia.

The dog possesses hepatic and sublobular veins which have unusually powerful sphincteric " throttle " mechanisms. It is conceivable that such sphincteric mechanisms are activated during total venous occlusion and that the picture of centrolobular congestion and necrosis is in some way related to this. Similar experiments were therefore carried out in cats which do not possess the sphincteric mechanisms seen in the dog. The cat liver has a sacculosinusoidal structure almost identical with that in the human, unlike the dog, which has a liver of tubulosinusoidal structure (Elias, 1949). Circulatory occlusion in cats cooled to 26° C caused the same rise of central venous pressure as that similarly produced in the dog. The derangement of hepatic function revealed after rewarming by galactose clearance tests was as severe as that in the dog. It is interesting, however, that the histological appearance of the cat liver was not even superficially similar to that of the dog subjected to the same procedure of cooling, circulatory arrest and rewarming. The main histological feature of the cat liver was extensive vacuolation of the centrolobular cells with some necrosis. The liver sinusoids, though swollen, betrayed none of the severe congestion and extravasation seen in the dog liver. Hence the evidence of functional damage in the cat liver revealed by galactose clearance tests can be correlated with the rise of central venous pressure during circulatory arrest which we believe to be responsible for the damage; the structural picture revealed by the liver shows a species difference.

The central venous pressure was measured in one patient in the period of circulatory arrest during intracardiac operation (under hypothermia) by Sir Russell Brock. In this period the central venous pressure rose to over 30 mm Hg (i.e. 40 cm H_2O). Hepatic function tests have not so far been carried out. Histological examination of human livers of patients who have succumbed following the operation has been made in only three instances. In none of these cases, however, was the liver specimen removed within 24 hours post mortem. It is difficult to compare the results with those obtained on the animals in which liver specimens were removed prior to sacrifice of the beast. Be that as it may, the human liver specimens showed none of the gross changes seen in those from the dog.

In summary it can be stated that experimental animals submitted to a procedure which closely mimics that experienced by patients undergoing intracardiac operation during hypothermia, on rewarming reveal a severe metabolic acidosis and a serious reduction of liver function. If congestion of the liver be prevented during circulatory arrest, liver function on rewarming is restored to normal. The metabolic acidosis is much less severe in these conditions. The human cases studied during and after intracardiac operation under hypothermia betray the same picture of severe metabolic acidosis. The rise of central venous pressure which we believe to be mainly responsible for the derangement of hepatic function is of an even greater order in the patient during circulatory arrest

than in the experimental animals. We consider it likely that hepatic functional studies carried out in patients will reveal an impairment similar to that described in the animals.

Though we have concentrated on investigations of liver function in our experiments, there is every reason to suppose that other viscera are affected untowardly by congestion and anoxia during circulatory arrest. Thus histological examination of the kidneys removed from two of our dogs has shown that extraordinary congestion of the cortex occurs. Glomerular extravasation of blood is widespread. The tubular lumina contained blood cells. The tubular cells showed cloudy swelling. It would be interesting to extend the histological investigations in an examination of the suprarenal glands.

Finally, we believe that these results of liver damage and metabolic acidosis produced by circulatory arrest during hypothermia can influence only the immediate prognosis. Regenerative powers of the liver are well established; the resumption of metabolic activity by the tissues at normal body temperature coupled with the restoration of renal function will soon dispel the metabolic acidosis. Our point rests in indicating that the patient may not survive.

SUMMARY

(1) *In vitro* studies on blood show that the pH of blood equilibrated at a given pCO_2 is unaltered by the temperature of equilibration provided that such pH measurements be made at the temperature of e uilibration.

(2) In animals subjected to hypothermia, thoracotomy and circulatory arrest, a severe metabolic acidosis develops on rewarming. Similar findings have been obtained in human patients undergoing open cardiac surgery under hypothermia.

(3) In animals under hypothermia circulatory arrest for ten minutes produces a severe derangement of liver function and structure. On rewarming the liver function is not improved. These findings may be correlated with our demonstration of a marked rise of central venous pressure produced during circulatory arrest.

(4) By preventing the rise of central venous pressure during circulatory arrest, liver damage may be avoided. On rewarming liver function is apparently normal; this recovery of liver function appears to be associated with an improvement in the metabolic acidosis.

ACKNOWLEDGMENTS

We wish to thank Sir Russell Brock for co-operation in allowing us access to his patients.

Figures 1, 2, 3, 4, have been previously published as illustrations in an article in *Guy's Hospital Reports*. We are grateful to the Editor of that journal for his courtesy in allowing us the use of these figures.

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EFFICIENCY OF CARBON DIOXIDE ABSORPTION BY SODA LIME IN A CLOSED SYSTEM

BY

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INTRODUCTION

CARBON DIOXIDE accumulation during general anaesthesia continues to be a serious problem to the anaesthetist. The present investigation, which aimed at determining the efficiency of soda lime, seems to indicate that the technique for carbon dioxide removal may be more important than is generally believed.

METHODS

The efficiency of the carbon dioxide absorption by soda lime was determined in the following way.

(1) "Circle" breathing.

In six experiments, a subject breathing through a Waters canister fully packed with 425 g of fresh soda lime was connected to a closed circuit spirometer as described by Erikson *et al.* (1951). The expired air then passed the canister before entering the spirometer where the amount of carbon dioxide not absorbed by the soda lime was determined.

This was achieved by circulating the expired air through an absorption unit with 10 per cent KOH. In this unit, where temperature and vapour pressure are constant, carbon dioxide was completely removed and recorded volumetrically with an accuracy of ± 5 ml. The inspired air was also drawn through the canister. The ventilation and oxygen consumption of the subjects were simultaneously determined.

The resistance of the spirometer is negligible, only 2 to 3 mm of water.

The carbon dioxide absorption in two different brands of widely used soda lime was compared. Both these brands were from manufacturers of high reputation and filled the requirements set for soda lime for anaesthetic purposes.

The regeneration of the activity of the soda lime was investigated in some experiments, inserting "resting periods" of 40 minutes several times during the experiments (in one case the "resting period" was 24 hours).

In one experiment the absorbing efficiency during increased metabolism due to exercise (250 kg-m/min on a bicycle ergometer) was determined.

(2) "To and fro" breathing.

In two experiments the efficiency of carbon dioxide absorption in a "to and fro" breathing system was determined by analysing the carbon dioxide content in samples of inhaled air using an experimental arrangement as shown in figure 1.

Oxygen was supplied continuously in order to maintain a convenient volume of

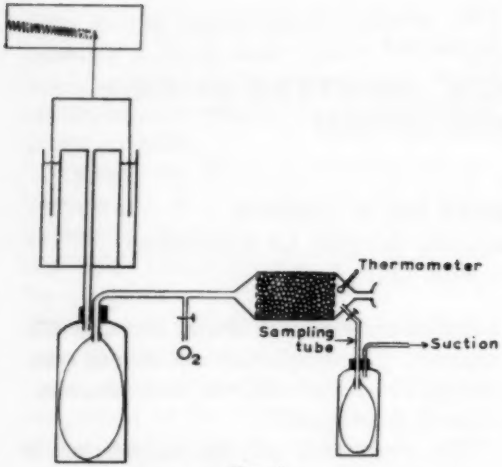

FIG. 1
Experimental arrangement for "to and fro" breathing.

the bag. The bag was placed in a closed bottle connected to a spirometer bellow, thus obtaining tracings of tidal volume and ventilation. At regular intervals the mouthpiece was closed and the subject disconnected from the apparatus. Applying suction, a volume equal to the tidal volume was drawn into a rubber bag through a sampling tube, thoroughly mixed and analysed for oxygen and carbon dioxide content in a Scholander "$\frac{1}{2}$-c.c. analyser". The accuracy of this method is ± 0.015 per cent.

RESULTS

(1) *Carbon dioxide absorption during "circle" breathing.*

Table I shows the results from one experiment. "Absorption efficiency" is the amount of carbon dioxide absorbed by the lime expressed as a percentage of the amount produced by the subject. The carbon dioxide output was calculated from the R.Q. value found when the subject was breathing in the spirometer without canister and the oxygen consumption determined during the actual experiment. R.Q. was assumed to be constant throughout the experiment.

The "absorption efficiency" in four experiments on the same subject, using two different brands of soda lime is listed in table II.

Table III shows the results from an experiment performed in order to investigate a possible "regeneration" of the soda lime. The data do not indicate regeneration of this soda lime when resting periods of 40 minutes were used.

In table IV the data obtained during exercise are listed. The work performed was 250 kg-m/min during the whole experiment. After 90 minutes the experiment was interrupted. Twenty-four hours later the same soda lime was used in the same subject for another 90 minutes. Neither in this case could "regeneration" be demonstrated.

Carbon dioxide absorption during "to and fro" breathing.

The data from two experiments on the same subject using two different brands of soda lime are given in table V. Corresponding to the rising carbon dioxide in inspired air a considerable increase of ventilation was observed.

Air temperature in the canister.

A mercury thermometer was placed in the canister close to the mouthpiece, and the temperatures observed in all experiments. Air temperature ranged from 37°C to 39.5°C. The correlation between the temperatures and the absorption efficiency of the soda lime was poor (see fig. 2).

TABLE I

Data from one "circle breathing" experiment using soda lime A.

Minutes	Ventilation l./min	O_2 uptake ml/min	CO_2 output ml/min	Unabsorbed CO_2, ml/min	CO_2 "absorption efficiency"
					per cent
0–5	12.0	340	280	38	86
26–30	12.3	330	270	40	85
56–60	12.5	400	330	75	77
86–90	13.5	350	290	74	74
116–120	13.4	390	320	92	71
146–150	14.9	380	310	112	64
Without canister	10.4	305	250	R.Q. = 0.82	

TABLE II

CO_2 "absorption efficiency" of soda lime A and B.

	Soda lime A				Soda lime B			
Minutes	Ventilation, l./min	CO_2 absorption efficiency	Ventilation, l./min	CO_2 absorption efficiency	Ventilation, l./min	CO_2 absorption efficiency	Ventilation, l./min	CO_2 absorption efficiency
		per cent		per cent		per cent		per cent
0–5	12.0	86	12.9	92	11.1	82	12.0	88
26–30	12.3	85	9.6	90	11.8	55	10.6	70
56–60	12.5	77	12.7	74	13.9	61	13.2	50
86–90	13.5	74	12.4	72	13.5	42	12.1	61
116–120	13.4	71	12.9	61	13.7	43	12.9	57
146–150	14.9	64	13.2	64	15.1	32	15.9	54

TABLE III

"Regenerating activity" of soda lime (type A)

Minutes	Ventilation l./min	O_2 uptake ml/min	CO_2 output ml/min	Unabsorbed CO_2 ml/min	CO_2 "absorption efficiency"
					per cent
0–10	10.1	350	290	41	86
30–40	8.5	340	290	53	82
*					
0–10	9.1	360	300	61	80
30–40	9.0	290	240	52	78
*					
0–10	9.7	370	310	58	81
30–40	8.7	330	280	72	74
*					
0–10	10.0	300	250	51	80
30–40	11.0	280	240	73	70
*					
0–10	11.4	290	240	72	70
30–40	9.8	250	210	65	69
Without canister	9.2	260	219	R.Q. = 0.84	

* Intervals of 40 minutes.

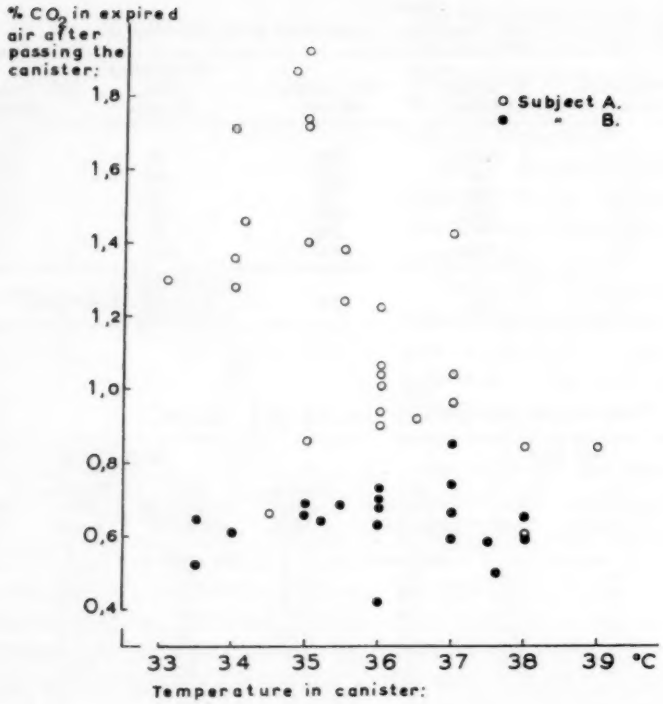

FIG. 2

Air temperatures in the canister and percentage carbon dioxide in expired air after passing the canister. Two subjects.

TABLE IV

CO_2 "absorption efficiency" during exercise, 250 kg-m/min, using soda lime B.

Minutes	Ventilation l./min	O_2 uptake ml/min	CO_2 output ml/min	Unabsorbed CO_2 ml/min	CO_2 "absorption efficiency"
					per cent
0–5	24.6	800	700	170	76
26–30	25.2	840	740	310	58
56–60	28.5	840	740	340	54
86–90	32.4	920	810	440	46
*					
119–122	28.5	760	670	430	36
141–150	31.0	820	720	480	33
171–180	32.3	880	770	560	27
Without canister	24.2	794	695	R.Q. = 0.88	

*Interval of 24 hours.

TABLE V

Carbon dioxide percentage in inspired air using a "to and fro" system with two different brands of soda lime.

Minutes	Brand of soda lime	Ventilation, l./min	Tidal air, ml	Respiratory rate	Percentage CO_2 in inspired air
2	A	9.0	450	20	0.53
2	B	8.7	460	19	0.22
60	A	10.1	560	18	0.73
60	B	10.2	510	20	0.53
120	A	12.8	640	20	1.10
120	B	13.9	730	19	1.21
180	A	14.1	670	21	1.59
180	B	19.2	1010	19	2.85

DISCUSSION

Our experiments, primarily designed to investigate the relative efficiency of two different brands of soda lime, showed absorption—even during rest—to be much less efficient than would be expected considering that "high quality" soda lime was being used. Some remarks on the use of soda lime in a closed system in general thus seem justified.

Our experimental conditions may not be ideal. In our "circle breathing" experiments, for instance, the amount of unabsorbed carbon dioxide was removed in the spirometer and thus did not accumulate in the system (and in the patient). It should be noted, however, that since inspiratory air is drawn through the canister "dead space" in the system will increase gradually as the soda lime gets exhausted.

Carbon dioxide production was probably higher in our subjects than would be generally expected in anaesthetized patients.

Many of the previous reports on the efficiency of carbon dioxide absorption have been based on the results of experiments performed with mechanical models. These have the advantage of permitting variable factors to be altered at will. Such experiments, however, can never quite reproduce the conditions encountered in our patients.

It is well known that the more exactly the tidal volume is accommodated in the intergranular space in the canister, the better the absorption. In our experiments, performed during rest, no definite correlation was found between absorption efficiency and tidal volume. One reason why such a correlation could not be demonstrated might be the fact that both tidal volume and respiratory rate are apt to change rapidly during the experiments. Such changes, however, often also take place in anaesthetized patients.

On the other hand a completely closed system is rather seldom used by anaesthetists. We are also aware that the way the widely used controlled or assisted respiration is carried out will influence carbon dioxide absorption.

The most remarkable feature of our experiments is the relative inefficient carbon dioxide absorption by the soda

lime. This is particularly noteworthy in the "to and fro" experiments. In these last experiments the unabsorbed carbon dioxide will accumulate in the system. The increase in tidal volume, noticeable already during the first hour, has also contributed to reducing the absorption efficiency.

There are few statements on what might be considered an innocuous concentration of carbon dioxide in inspired air. The concentrations found in our experiments must be considered high, however, and exceed by far the arbitrary maximum of a "permissible" concentration of 0.2 per cent as recently set by Woolmer and Lind (1954). Mousel *et al.* (1946) use the value of 0.6 per cent as an indication for the end point of efficient absorption by the soda lime.

With regard to the comparison of the two brands of soda lime, brand A points itself out as the better, both with regard to absorption efficiency and duration of action. If the prices of the limes are taken into consideration, however, one would for the same expense get more carbon dioxide absorption out of the least efficient soda lime (B). According to Adriani and Rovenstine (1941) regeneration of the activity of soda lime may occur a number of times if allowed to stand unexposed to carbon dioxide for half an hour or more. This phenomenon is explained by the fact that sodium hydroxide, the more active and soluble alkali in the lime, preferentially forms carbonate. Then an interaction between sodium carbonate and calcium hydroxide takes place, and sodium hydroxide regenerates on the surface of the granules, thus reactivating absorption.

Mousel *et al.* (1946) on the other hand maintain that the amount of moisture present in the soda lime controls the activity, and when regeneration takes place during a rest period, this is the result of moisture being condensed and redistributed on the particles of the absorbent.

We will not place too much emphasis on the fact that our experiments failed to show evidence of regeneration after resting periods of 40 minutes, but we would like to point out that an "apparent regeneration" may well be explained without taking a "chemical regeneration" of the lime into consideration. For instance, when handling the canister the granules of the soda lime may easily change position. In this way previously unexposed surfaces and granules may come in contact with the gas stream, thus improving the performance of the canister. A decrease of the absorption efficiency may also occur for the same reason as a result of handling, as recently described by Robson and Pask (1954). These workers also stress the importance of a correct packing of the lime, and the usefulness of applying a certain degree of compression on the granules to avoid channelling and improve absorption efficiency.

In our experiments care was taken to avoid shaking of the canisters.

Considering the many variable factors involved in carbon dioxide absorption and the well-known difficulties in detecting carbon dioxide accumulation in anaesthetized patients (carbon dioxide concentration as high as 2 per cent may pass unrecognized) we feel that further studies, which should aim at obtaining a

better control of carbon dioxide during anaesthesia, are desirable. Our studies indicate that, in a closed system, carbon dioxide absorption by means of soda lime is not a sufficiently reliable method.

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BOOK REVIEW

Symposium on Sedative and Hypnotic Drugs. Published by Baillière, Tindall and Cox. Pp. 111; illustrated. Price $3.50.

It would be difficult to over-emphasize the value of this type of volume. We are familiar with the excellent reports of symposia published by the New York Academy of Science, and in these days of rapid advancement they are of continual assistance to the busy practitioner in his efforts to keep abreast of the times. Sometimes their emphasis is rather towards the very academic aspects of their subject, and the practical clinician, as opposed to those working in University Centres, might find these reports of little immediate application. The volume under review is a verbatim report on a symposium on Sedative and Hypnotic Drugs organized by the Miles-Ames Research Laboratories and the Sumner Research Laboratories, to mark the opening of their new premises. It is full of interest to all who practise the specialty of anaesthesia.

There are six chapters, two or three of which might be found rather hard going for the clinician; but the discussions which are reported following each chapter are not the least interesting parts of the symposia.

Dr. H. W. Magoun writes the first section on "A Neural Basis for the Anaesthetic State" and he reviews the modern approach to the present-day knowledge of the mode of action of anaesthetics. This is followed by an up-to-date account by Dr. D. E. Green of the relation of the mode of action of the sedative and hypnotic drugs to the intracellular respiratory enzymes. The pharmacological evaluation of sedative and hypnotic drugs is reviewed in the next chapters and the difficulties concerned with their clinical assessment.

The point is substantially made by Dr. Heath that the clinical assessment of the relative effectiveness of various analgesics is really based on subjective observations which are conditioned by the subjective psychological state of the patient or subject, whose reactions are influenced by his psychological stress at the time of the experiment. A method of objective assessment using the electro-encephalograph is proposed.

The book ends with a report of a panel discussion which is of the greatest interest and contains an excellent summary by Dr. W. K. Livingstone of the whole symposium.

The contributors to the volume are of the highest standing in their subjects and each contribution to the discussion is assisted by a photograph of the author.

Perhaps it is surprising to find no discussion of the new antagonists to sedative and hypnotic drugs and certainly those who are looking for a detailed summary of the relative values of the numerous morphine and barbiturate derivatives now available will be disappointed. Nevertheless this is a book which can be honestly recommended to all who are practising the specialty of anaesthesia, and who aspire to be something more than technicians.

T. Cecil Gray

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CARBON DIOXIDE CONCENTRATION IN VARIOUS ANAESTHETIC TECHNIQUES

BY

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FOLLOWING the observation of Harrison and Jones (1955) on the concentration of carbon dioxide in gas samples taken from two points on a Boyle's machine during the administration of anaesthesia by a semi-closed method, it was thought that it might be enlightening to extend the investigation to other techniques and machines.

For this purpose, use was made of the recently available Carbon Dioxide Analyser made by the British Oxygen Co. Ltd. This apparatus operates on the principle of a colour change in a special solution, the tint of which varies with the concentration of carbon dioxide, in the gas sample.

The readings expressed in percentage form, are: 0.3, 0.7, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0.

Naturally one would not expect the degree of accuracy with this apparatus that one would from analyses carried out by Haldane's method but, if that claimed by the manufacturer is justified, one can certainly obtain most useful information by which to compare various techniques.

Each experiment was repeated in ten consecutive patients when an identical technique was employed and the results tabulated. The readings were taken in the middle of the anaesthetic when the operation was in progress and no attempt has been made to evaluate changes in carbon dioxide concentration during induction, etc., so that the results represent "running levels" only. Fresh soda lime was used as, obviously, exhausted soda lime would affect the readings.

Using a Coxeter-Mushin absorber, the analyser was plugged into the circuit first at the junction of the expiratory and then of the inspiratory valves with the corrugated tubing leading to the patient.

In the first experiment a completely closed circuit was employed with a basal feed of 200 ml of oxygen and the circulating gases passing through the ether chamber.

Readings were as follows:

TABLE I

Coxeter-Mushin absorber. Closed circuit. 200 ml oxygen, ether. Absorber on.

Inspiratory side per cent	Expiratory side per cent
1.5	4.0
2.0	5.0
2.5	5.0
2.5	4.0
2.5	4.0
2.5	4.0
2.0	5.0
1.5	4.0
1.5	4.0
1.5	5.0
Average 2.0	4.4

Using the Medical and Industrial Equipment absorber in the same way with a basal oxygen flow of 200 ml, and

the ether chamber in circuit, the results were as follows:

TABLE II

M.I.E. absorber. Closed circuit. 200 ml oxygen, ether. Absorber on.

Inspiratory side per cent	Expiratory side per cent
0.1	4.0
0.7	3.5
0.7	3.5
0.7	2.5
0.7	4.0
0.7	3.0
0.7	3.0
0.7	4.0
0.7	4.0
0.7	3.0
Average 0.6	3.5

The next technique employed was one involving complete manually controlled respiration with the Medical and Industrial Equipment absorber in circuit and a high gas flow of nitrous oxide 6 litres, and oxygen $1\frac{1}{2}$ litres per minute. A purposeful leak was permitted.

The patient was under pethidine-nitrous oxide anaesthesia with relaxation produced by tubocurarine. The results were as follows:

TABLE III

M.I.E. Absorber. Closed circuit with leak. Nitrous oxide 6 litres. Oxygen $1\frac{1}{2}$ litres. Absorber on. Pethidine. Tubocurarine. Manual control.

Inspiratory side per cent	Expiratory side per cent
0.3	1.5
0.3	2.0
0.7	1.5
0.3	2.0
0.3	2.5
0.7	1.5
0.7	2.0
0.7	2.0
0.7	2.0
0.3	2.0
Average 0.5	1.9

Using the same technique with a Coxeter-Mushin absorber it was found that the carbon dioxide content of the expiratory sample was higher, the average reading being 3.5 per cent.

The identical method was next employed using the M.I.E. absorber, but a mechanical respirator was substituted for manual control. This took the form of a Beaver respirator with a 1000-ml rubber bag placed between the exit port of the respirator and the M.I.E. absorber unit. The expiratory valve on the T-piece leading to the endotracheal tube was adjusted so that an inspiratory pressure of 18-20 mm Hg could be built up.

The readings are as in table IV.

TABLE IV

M.I.E. absorber. Closed circuit with leak. Nitrous oxide 6 litres. Oxygen $1\frac{1}{2}$ litres. Pethidine. Tubocurarine. Mechanical respiration.

Inspiratory side per cent	Expiratory side per cent
0.3	2.0
0.3	1.5
0.3	2.5
0.3	2.5
0.3	2.5
0.7	3.0
0.7	2.5
0.3	2.5
0.3	2.5
0.3	2.0
Average 0.4	2.4

It was next decided to keep the total gas flow at $7\frac{1}{2}$ litres but to leave the soda lime out of circuit. It was found that there was no great build-up of carbon dioxide on the expiratory side of the circuit, although this did rise. Presumably this rise would have been less had the total gas flow been greater.

Naturally the sample taken on the inspiratory side rose, as the gases now had not just passed through the soda-lime canister.

The results are shown in table V.

TABLE V

M.I.E. absorber. Closed circuit with leak. Nitrous oxide 6 litres, oxygen 1½ litres. Absorber off. Pethidine. Tubocurarine. Mechanical respiration.

Inspiratory side per cent	Expiratory side per cent
2.5	3.0
2.5	3.0
2.5	3.5
2.0	3.0
2.5	3.0
2.5	3.0
2.5	3.0
2.5	3.5
2.0	3.0
2.5	3.0
Average 2.4	3.1

Finally, a partial rebreathing technique was used, employing the standard Magill rebreathing attachment with nitrous oxide 6 litres, oxygen 1½ litres and trichlorethylene. Samples were taken from the junction of the corrugated rubber tubing and the face-piece. The results are expressed in table VI.

TABLE VI

Boyle's machine. Semi-closed circuit. Magill attachment. Nitrous oxide 6 litres, Oxygen 1½ litres. Trichlorethylene.

per cent
3.0
2.5
3.0
3.0
3.0
4.0
4.0
4.0
3.0
4.0
Average 3.4

As might be expected with this technique, if the total gas flow were reduced, the carbon dioxide level at the mask will increase, and readings beyond 5 per cent can be obtained, whereas, if the total gas flow were increased to minimize the amount of rebreathing, readings at the mask will fall to less than 1 per cent. Thus this analyser can be used to determine the "critical flow" of a given apparatus.

The above experiments do not claim to be either extremely accurate or exhaustive; but now that a simple and cheap analyser has become available the assessment of carbon dioxide levels can readily be determined by the anaesthetist with whatever apparatus or method he chooses to employ; and it is hoped that they will give some indication as to what is happening to the carbon dioxide levels in some commonly employed techniques.

It is further suggested that an analysis of carbon dioxide content of gas samples will be extremely useful in cases of prolonged apnoea following anaesthesia and at the end of lengthy chest operations.

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Brit. J. Anaesth. (1956), **28**, 23

CONTROLLED RESPIRATION: STANDARDIZATION OF VENTILATION

BY

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THE technique of controlled respiration during anaesthesia was developed primarily to deal with respiratory inadequacy enforced on the patient by an open pneumothorax. This paper is concerned with developing means to adjust the volume of passive ventilation to a physiological level, the basis at present appearing to be entirely empirical.

Originally, in order to institute controlled respiration, active respiration was abolished in two ways or by a combination of the two (Nosworthy, 1941).

(1) By depressing the sensitivity of the respiratory centre, especially to carbon dioxide, by anaesthetics or other drugs.

(2) By reducing the carbon dioxide tension in the arterial blood by hyperventilation. In addition it is possible that artificial inflation abolished the patient's respiratory efforts by affecting the Hering-Breuer mechanism.

At a later date curarizing drugs came into use and, by paralysing the respiratory muscles, made it easier for the anaesthetist to take over the patient's external respiration. The widespread use of these drugs now provides the most frequent and essential indication for the use of controlled respiration.

The first two conditions suggest that assisted respiration may not have much practical application: during anaesthesia the respiratory centre is almost invariably depressed by anaesthetics or other depressant drugs. Recent observations revealed that during anaesthesia by thiopentone, pethidine, nitrous oxide and oxygen the alveolar carbon dioxide tension tended to stabilize at about 50 mm Hg (equivalent to 7 per cent carbon dioxide). If under these conditions the respiration is assisted in any efficient way the carbon dioxide tension will fall, so that the second mechanism will act and apnoea will result with full controlled respiration a necessity. In favour of assisted respiration it has been suggested that retention of some spontaneous respiratory effort is advantageous to the circulation; certainly the manner of artificial ventilation and the mean pressure in the respiratory tract are important if the circulation is not to be impaired (Cournand *et al.*, 1947; Werkö, 1947), but the present communication is not concerned with these considerations.

CARBON DIOXIDE RETENTION

The function of respiration is the supplying of oxygen and the elimination of carbon dioxide—these two are not syn-

onymous, nor is the assurance of one a guarantee that the other is satisfactory. In experiments on diffusion respiration (Roth *et al.*, 1947), dogs placed in an atmosphere of oxygen and saturated with oxygen were made apnoeic with anaesthetics, yet they remained well oxygenated indefinitely by virtue of the haemoglobin oxygen pump and minimal ventilation by cardiac movements; there was, however, a progressive rise in carbon dioxide tension to very high levels (250 mm Hg), death finally resulting from carbon dioxide poisoning.

Under anaesthesia similar conditions often prevail: there is an oxygen-rich atmosphere and an oxygen-rich patient who will remain a good colour with minimal respiratory movements or none for many minutes. It is evident that in such patients carbon dioxide levels may mount (Jooste, 1955). Even apart from such gross respiratory depression a tendency to carbon dioxide retention is ever present during anaesthesia (Harbord *et al.*, 1953; Ellison, 1955). An oxygen-rich atmosphere, by reducing respiratory drive (Shephard, 1955), and by effects on carbon dioxide carriage, will of itself tend to cause carbon dioxide retention. Indeed, in subjects with chronic respiratory acidosis, oxygen administration by removal of the anoxic respiratory drive can precipitate carbon dioxide narcosis (Donald, 1953) and depression, a danger insufficiently appreciated (Mushin, 1955). Ill effects from hypercapnoea may include cardiac arrhythmias (Johnstone, 1950) and cardiac arrest, hypertension and vascular incidents, "cyclopropane shock" (Dripps, 1947), and self-perpetuating depression (Scurr, 1954). Effects on the electroencephalogram have been reported recently (Clowes, 1953). When the alveolar carbon dioxide level attains 9 per cent (in unanaesthetized subjects) respiratory stimulant effects are maximal—further increase leads to progressive depression. The stimulant effects may be masked completely by anaesthetic drugs (especially curarizing agents) but a tracheal tug on respiration is always a suggestive sign. Carbon dioxide accumulation with depression in the postoperative period (Scurr, 1954) may be a cause of postoperative death with minimal autopsy findings (Pask, 1955).

Supposing instead of an oxygen-rich mixture during anaesthesia air or 20 per cent oxygen with 80 per cent nitrous oxide be used for ventilation: if the patient remains a good colour (in the absence of anaemia, etc.), is it a guarantee of satisfactory carbon dioxide balance? Calculation shows (Affeldt *et al.*, 1955; Fenn *et al.*, 1946) that under such conditions hypoventilation such as to double the alveolar carbon dioxide tension (40 mm Hg→80 mm Hg) reduces the alveolar oxygen tension to 54 mm Hg. The oxyhaemoglobin dissociation curve reveals that this represents about 80 per cent saturation in the arterial blood which is just about the cyanosis threshold, i.e., the carbon dioxide tension may be doubled (equivalent to 11–12 per cent alveolar carbon dioxide) before cyanosis provides a warning of hypoventilation.

PHYSIOLOGICAL CONSIDERATIONS

In the resting individual pulmonary ventilation is adjusted to the rate of metabolism; the link between metabolism and breathing is mainly the alteration in

the carbon dioxide tension of the blood, to which the respiratory centre is exquisitely sensitive unless anaesthesia interferes with its sensitivity or blocks the operation of the ventilatory muscles. When the inspired carbon dioxide is negligible and conditions are steady the alveolar ventilation required may be defined in terms of the carbon dioxide production and the alveolar carbon dioxide concentration, as follows:

$$\text{Alveolar ventilation per minute} = \frac{\text{Volume of } CO_2 \text{ produced per minute}}{\text{Alveolar } CO_2 \text{ fraction}}$$

e.g., in a patient producing 200 ml CO_2 per minute, to maintain alveolar CO_2 at 5 per cent:

$$\text{Alveolar ventilation per minute} = \frac{200}{5/100} = 4 \text{ litres per minute.}$$

The physiological level of the carbon dioxide fraction in alveolar air is 5.6 per cent (representing 40 mm Hg tension) and this is normally the level which artificial ventilation during anaesthesia should be adjusted to maintain.

Carbon dioxide output can be calculated from published data of metabolic rate (Benedict and Talbot, 1921) and thus a graph can be drawn to show carbon dioxide production based on body weight (Radford, 1955), this being the simplest basis for use during anaesthesia, although allowances must be made for the usual sources of error in body weight calculations.

The actual alveolar ventilation per minute is given by the following equation:

$$\text{Alveolar ventilation per minute} = (\text{Tidal air} - \text{Dead space}) \times \text{Respiratory rate per minute}$$

The anatomical dead space can also be calculated from the body weight (Radford, 1955) and by happy chance is found to be equal to 1 ml per pound body weight. (Disease, e.g., emphysema, or partial inflation of the lungs by constant pressure in the anaesthetic bag can grossly increase the dead space effect and predispose to carbon dioxide retention (Siebecher *et al.*, 1954; Crafoord, 1938).) Note the important effect of dead space multiplied by respiratory rate on the minute volume. Thus from body weight, (1) carbon dioxide output and (2) dead space can be calculated: the physiological carbon dioxide fraction being known, if a ventilation rate now be chosen (e.g. 20 per minute) the equations can be solved to give the tidal air necessary for a patient of given weight at the chosen respiratory rate. From these data Radford (1955) has constructed a nomogram to provide ventilation standards for use during artificial respiration and anaesthesia. To provide an example from Radford's nomogram:

Male, 150 pounds: rate = 20 per minute, tidal air needed = 350 ml, i.e. total minute volume = 20 × 350 ml = 7 litres.

Therefore, if during anaesthesia an approximately constant rate of ventilation (e.g. 20 per minute) be maintained some method of measuring the total minute volume could be employed to implement the calculated standard ventilation.

MEASUREMENT OF VENTILATION DURING ANAESTHESIA

Various types of apparatus have been tried and found suitable for the purpose of measuring the total minute volume of ventilation:

(1) Dry Gas Meter, Type D.1 (Parkinson and Cowan Industrial Products, London). This type of apparatus is inexpensive but cumbersome, the resistance is very low and it is placed across the inspiratory tube of the circle absorption apparatus.

(2) Bennett Ventilation Meter.

(3) The Jet Anemometer (Wright, 1955; Leader in *Brit. med. J.*, 1955). This apparatus is compact, light and of low resistance. It seems highly suitable for incorporation in anaesthetic circuits to monitor the minute volume of ventilation.

(4) A volumetric rebreathing bag or bellows which shows the tidal volume, e.g. the Blease Pulmoflator or the apparatus of Eastwood and Harbord (1954). A new type of bellows which can be set for a given tidal volume is at present being developed.

These instruments can also be used to check the level of spontaneous ventilation at the end of operation to see if it is adequate and so avoid the perils of respiratory depression in the recovery period.

Application of calculated ventilation volumes during anaesthesia and check estimation of alveolar carbon dioxide levels by the Draeger carbon dioxide analyser has so far demonstrated very satisfactory conformity.

Checks on ventilation levels attained during controlled respiration by various anaesthetists have shown that, apart from the risk of underventilation, in other hands hyperventilation is common.

Minute volumes of 10 to 12 litres per minute were often observed; these would often produce double the required amount of alveolar ventilation. The possible dangers of such excessive ventilation have been pointed out (Mushin, 1955; Campbell, 1953), but are probably less than those of underventilation (Pask, 1948). Changes in blood pH have been noted during anaesthesia as a result of hyperventilation (Dundee, 1952); among other results the skin may be pale cold and moist (Wright, 1945); the significance of the Bohr effect in causing oxygen lack has not been fully assessed. Depletion of the total body store of carbon dioxide assessed at 25 to 30 litres (Spurrell, 1955) may take some time, and presumably would be detected first by a fall in carbon dioxide levels in a sample of mixed venous blood; reports on such changes in body carbon dioxide stores are now available (Rahn and Farlie, 1955).

SUMMARY

The assessment of ventilation during anaesthesia with controlled respiration rests at present on an empirical basis.

The alveolar ventilation required can be estimated from physiological data.

Means are suggested for observing ventilation volumes during anaesthesia so that the risks of hypoventilation and hyperventilation can be avoided.

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DIRECTOR OF THE RESEARCH DEPARTMENT OF ANAESTHETICS of the FACULTY OF ANAESTHETISTS of the ROYAL COLLEGE OF SURGEONS OF ENGLAND

Applications are invited for the post of Director of the Research Department which is being formed in the College by the Faculty.

Applicants must be anaesthetists and hold the F.F.A.R.C.S. or comparable higher degree or Diploma in Anaesthetics. Arrangements will be made for the Director to hold an Honorary Consultant appointment at a suitable hospital.

The salary will be in the range applicable to University Clinical appointments; and its starting point within this range will be determined by the age, qualifications and experience of the successful candidate. The usual family allowances will be payable, and the salary will be subject to superannuation.

Applications (fifteen copies) together with the names of two referees should be sent not later than February 1, 1956, to Mr. W. F. DAVIS, Secretary, Faculty of Anaesthetists, Royal College of Surgeons of England, Lincoln's Inn Fields, London, W.C.2, from whom further particulars may be obtained.

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A NEW SODA LIME

BY

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A NEW brand of soda lime ("Durasorb") has appeared upon the market for which is claimed more prolonged carbon dioxide absorption and greater than usual freedom from dust. The following notes on a test of a sample may be of assistance to readers who are considering its clinical trial.

Carbon dioxide absorption was tested in the model assembly described in a previous paper (Robson and Pask, 1954). Briefly, "to and fro" ventilation of a Waters canister was carried out with a respiratory pump, at a tidal volume of 500 ml, 12 times per minute; 200 ml CO_2/minute were admitted to the "patient" side of the model and the "bag" gases were sampled continuously, through an infra-red gas analyser. In this arrangement, existing brands of soda lime behave consistently, giving results usually similar to that in line 1 (fig. 1).

The new lime gave the results shown in line 2. The sample permitted a single clinical trial. After 4 hours 10 minutes of intermittent use, no detectable CO_2 was found in the bag; after 5 hours 0.5 per cent and at 5 hours 10 minutes 1.4 per cent was found.

We feel that the formation of dust from soda lime is a drawback which has not yet been overcome. We do not think that it is simply a matter of the hardness of the soda lime. The soda lime we use at present is chosen for its relative freedom from dust rather than on grounds of endurance of absorption, since, in practice, soda lime seems usually to be discarded before exhaustion, for caution's sake. The new lime was compared with our present soda lime by shaking samples of each for five minutes in glass-stoppered bottles. The dust was then separated visually and weighed: 7.2 per cent of our existing soda lime seemed to have been reduced to dust and 6.6 per cent of the new sample.

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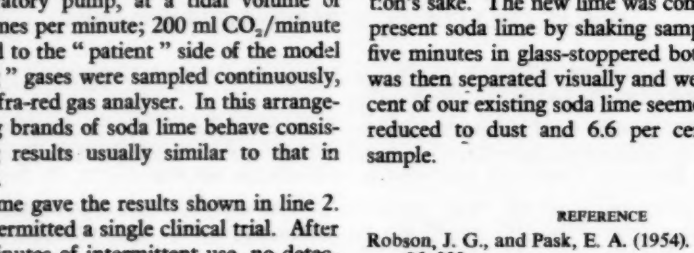

FIG. 1

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AN ATTEMPT TO FIND A PRACTICAL METHOD OF CARBON DIOXIDE MEASUREMENT DURING ANAESTHESIA

BY

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RECENTLY a great deal of attention has been focused on the problem of carbon dioxide accumulation during anaesthesia (Stead *et al.*, 1953; Harbord, and Lucas, 1953). A number of articles have appeared describing investigations on the actual figures for "alveolar air" or arterial carbon dioxide tensions found during anaesthesia. Ringrose *et al.* (1950) developed a carbon dioxide indicator showing a qualitative measurement of carbon dioxide in anaesthetic atmospheres. Harrison and Jones (1955) were unable to find, however, that this method has a practical value. Engell and Ibsen (1952) used a carbovisor based on a photoelectrical principle to obtain a continuous recording of carbon dioxide estimations during thoracic operations. Eastwood and Harbord (1955) correlated the changes in tidal volume with those of "alveolar air" concentrations.

Most of the methods described are impossible to perform routinely without assistance and the aid of a laboratory to do the analysis. The aim of this article is to show that it is possible to obtain measurements of the "end of expiration air" of sufficient accuracy to be of value to the anaesthetist working alone.

METHOD

A carbon dioxide meter, made in Germany and calibrated up to 10 per cent was used in the experiments. This machine is small and, being made of plastic, weighs very little. The principle is to aspirate a sample of air into a chamber of known volume which is then driven into a set volume of 25 per cent sodium hydroxide which rises into a graduated chamber. As the carbon dioxide is absorbed the level of the hydroxide falls in the measuring chamber and the figure is read off after a minute.

The reading given is apparently accurate up to 0.3 per cent. The indicator should be checked frequently against room air which should give a figure of 0 per cent. The machine should be handled as little as possible to prevent heat transference from the hand affecting the readings. The raising and lowering of the plunger should be done slowly and gently or the readings will be affected.

SAMPLING

The samples were obtained from the upper end of a cuffed endotracheal tube. A short glass tube with a short piece of

rubber tubing attached was fitted into the rubber bung of the endotracheal mount. This rubber tubing was kept clamped when sampling was not in process. Samples were taken at the end of expiration whether respiration was spontaneous or controlled. Henderson and Haggard (1925), Rahn and Otis (1947) and Buckley *et al.* (1952) have shown that the carbon dioxide content in samples of air taken at the end of expiration approximates to the pCO_2 of arterial blood.

ANAESTHETIC

All patients were premedicated with papaveretum 20 mg and scopolamine 0.45 mg. Induction was by thiopentone in doses of 200–400 mg. Relaxation was obtained by suxamethonium or gallamine triethiodide. Nitrous oxide and oxygen supplemented with pethidine maintained narcosis and analgesia in 25 cases. Five cases received cyclopropane.

Nitrous oxide is soluble in caustic soda but a number of experiments using samples from the mixture of oxygen 3 litres and nitrous oxide 6 litres per minute showed that an average figure of only 0.3 per cent need be deducted from the carbon dioxide readings to allow for the absorption of nitrous oxide by the caustic. This figure has been deducted in the data given below. Cyclopropane would appear to be insoluble in the caustic.

All measurements were taken by the same person but the anaesthetics were given by a number of anaesthetists. All operations were major, the majority either upper abdominal or thoracic. The blood pressure and pulse rates were recorded at five-minute intervals. The average duration of anaesthesia was two hours, the longest being three hours, the shortest one hour.

RESULTS

418 readings were taken during 30 anaesthetics. A normal figure for " alveolar air " has been described as 4.7–6.4 per cent by Eastwood and Harbord (1955). No attempt was made to compress the chest at the end of expiration as it was felt that this could hardly be described as routine procedure during anaesthesia. A practical difficulty was to be certain that the sample analysed was, in fact, an end of expiration sample and not a mixture of incoming gases and "alveolar air ". On a number of occasions in the early part of the experiment very low figures were obtained suggesting that this mixing had occurred or that the tidal volume was too low. These low figures were discarded. Some mixing was unavoidable and no doubt the figures recorded are slightly below the true figures. The results are tabulated in table I.

TABLE I

Carbon dioxide estimations of end-of-expiration gases

Type of respiration	Highest single recording	Lowest single recording	Average for the series
	per cent	per cent	per cent
Spontaneous:			
First 15 cases	8.9	4.2	7.0
Second 15 cases	7.2	3.7	5.9
Assisted	8.7	4.3	6.7
Controlled	7.2	2.4	4.4

(1) *Spontaneous respiration.*

In 50 per cent of the cases the readings were within the normal limits. The average reading for the remaining 50 per cent was above normal, i.e. 7 per cent indicating some degree of underventilation. It must be stated that most of these

high figures were obtained in the early part of the experiment as, later on, respiration was controlled when the carbon dioxide tension began to rise. No apparent ill effects were observed in these cases though the figures were not alarmingly high and the longest period during which hypercapnoea was permitted was only 25 minutes except in one case.

(2) *Assisted respiration.*

This technique was only used in the early part as it soon became obvious that the readings were just as high as when respiration was spontaneous.

(3) *Controlled respiration.*

Respiration was defined as being controlled when no respiratory movements were observed for 30 seconds on releasing the bag. It was difficult to be certain at what point control of respiration had been affected by carbon dioxide elimination as the factors affecting control are variable. On a number of occasions control had been gained when additional surgical stimuli produced respiratory movement. In one case the readings were 3.7 per cent when extra pressure on a retractor in the abdomen caused wrinkling of the forehead and respiration became spontaneous.

At the beginning of the series control of respiration was maintained at considerably varying levels, i.e. the lowest average was 3.3 per cent and the highest average 6.1 per cent, showing that the artificial ventilation had been inconsistent and that in some cases the patient had been overventilated, while in others either central depression had been excessive or the degree of muscular paralysis was high. In the latter part of the series control was maintained at levels of carbon dioxide in the region of " low normal ", i.e. 4.4 per cent.

In one case control was maintained for the first hour at a level of 3.8 per cent. Spontaneous respiration was then permitted for 25 minutes, with the absorber off, on a mixture of nitrous oxide 4 litres and oxygen 2 litres per minute. The carbon dioxide readings (nine in all) averaged 7.1 per cent, the highest being 8 per cent and the lowest 6.2 per cent. During the next hour respiration was again controlled but it was found difficult to get the readings down to 4.6 per cent during this second period of control.

Extremely high figures were obtained in a case of lobectomy. These readings are not included in table I. On three occasions figures of well over 10 per cent were found. The actual figures could not be determined as the meter is not calibrated to above 10 per cent. On these isolated occasions the respirations were controlled. Engell and Ibsen (1952) found figures of up to 16 per cent from time to time in chest operations and attributed these rises in some cases to obstruction of the lower respiratory tract by secretions.

CARBON DIOXIDE READINGS AND THE BLOOD PRESSURE

It was hoped that some correlation between the blood pressure, pulse rate and the carbon dioxide levels would be found. No obvious relationship was noticed, however, probably because the hypercapnoea was not excessive. Some hypertension, i.e. a systolic pressure persistently raised 25 mm Hg above the bed-resting level was encountered in three cases (all fit young men). In all three cases the carbon

dioxide readings were well within the normal range. Another case was allowed to maintain a carbon dioxide percentage of 6.3–7.5 per cent for 30 minutes but the blood pressure remained at the patient's normal level of 110/70 mm Hg. On the other hand low blood pressure readings were recorded in two other cases where the carbon dioxide readings were approximately 7 per cent during the same period. The pulse rate appeared to be affected far more by factors such as the depth of anaesthesia in relation to the degree of surgical trauma and the cardiac accelerator action of gallamine than by these degrees of change in the carbon dioxide concentration.

DISCUSSION AND CONCLUSIONS

The clinical assessment as to the adequacy of respiration, either spontaneous or controlled, is not always satisfactory.

Spontaneous respiration.

It is common anaesthetic practice to give inhaled mixtures containing more than 20 per cent oxygen. This obviously presupposes that ventilation will be inadequate or the extra oxygen would not be needed. Experience of positive pressure respiration in a poliomyelitis unit shows that even with total respiratory paralysis air alone is satisfactory provided that ventilation is adequate (Smith *et al.*, 1954; Lassen, 1953; Harries and Lawes. 1955). In fact extra oxygen is only needed in these cases during emergencies or where there is hyperpyrexia. Pask (1955) has pointed out the dangers of accepting spontaneous respiration as being adequate when depressant drugs or relaxants have been used. Cyanosis only indicates a high degree of suboxygenation. Lassen (1955) has stated that cyanosis occurs when the arterial oxygen saturation is reduced to approximately 82 per cent and it seems reasonable to assume that if the colour of the patient is used as the only guide to the presence or absence of suboxygenation then some degree of hypercapnia may have occurred long before cyanosis is evident. The degree of respiratory ventilation as assessed by the movements of the bag may be far from accurate. In one case intubation was performed under suxamethonium and the only drugs given after induction were pethidine 50 mg in two doses with nitrous oxide 6 litres and oxygen 2 litres. The carbon dioxide estimations were between 6.5 per cent and 7.2 per cent during the entire operation of one hour. In this case the movements of the bag appeared to be definitely satisfactory but, as the figures show, some degree of hypercapnoea had occurred.

Assisted respiration.

This method was only used in the early part of the series as the figures obtained were just as great as those found during spontaneous respiration. Pask (1955) points out that true assisted respiration is very difficult if not impossible to perform, and that properly assisted respiration soon becomes controlled respiration. If it is accepted that it is desirable to keep the carbon dioxide tension within normal limits there seems little reason for using this technique as a means of eliminating hypercapnoea.

Controlled respiration.

The control of respiration depends upon a number of factors which must vary

greatly in each individual case. These factors are—the sensitivity of the respiratory centre; the degree of muscular paralysis; the carbon dioxide tension of the arterial blood; the extent of the surgical stimuli and probably the state of activity of the stretch receptors. In a clinical condition which depends upon at least five factors it is extremely difficult to assess the role played by any single one of them.

As most anaesthetic agents depress the sensitivity of the respiratory centre to carbon dioxide the ideal level of carbon dioxide tension in controlled respiration would be within the normal range but unless some means is available to measure the pCO_2 or the percentage in "alveolar air" it is difficult to see how this ideal can be obtained. If relaxants or central depressants are the main factor in control then high "normal" carbon dioxide levels may occur. If carbon dioxide elimination predominates the patient may be overventilated, as respiratory movement can occur in overventilated patients in a light plane of anaesthesia if the surgical stimuli are proportionately excessive.

Carbon dioxide narcosis.

There are many illustrations in the literature of the narcotic action of carbon dioxide (Dripps and Comroe, 1947; Meduna, 1950). It has been used as an anaesthetic by Waters (1937) when one of the three cases described developed convulsions on the table. It must be emphasized, however, that in these cases where carbon dioxide was inhaled to produce unconsciousness the concentrations were extremely high. In the series described by Westlake *et al.* (1955), of carbon dioxide narcosis in emphysematous patients the majority had greatly raised carbon dioxide tensions in their arterial blood, i.e. over 100 mm Hg, though a number of patients were drowsy at figures around 80 mm Hg. On the other hand one patient was mentally alert when his arterial tension was 110 mm Hg, showing that the susceptibility of patients to carbon dioxide varies greatly.

The general effects of carbon dioxide excess.

The signs and symptoms of hypercapnoea are very protean and are dependent upon the degree of hypercapnoea and the susceptibility of the individual.

Gray and Fenton (1954) describe a case where presumed carbon dioxide excess caused delay in the return of normal respiration. In this case there was marked inadequacy of tidal air exchange compared with the forceful chest movement; tracheal and mandibular tug were much in evidence. Ibsen (1954) describes a rise in blood pressure, cold clammy skin, and gagging and bucking respiration with increased nasal and oral secretions as being due to carbon dioxide excess. Davies *et al.* (1955) suggest that in some cases of prolonged action of suxamethonium the cause may be due to hypercapnoea and describe lack of intercostal movement, tracheal tug and flaring of the nares. In their experiments with dogs they were able to reproduce the uncertain respiratory movements seen in their patients when the dogs received suxamethonium under conditions of hypercapnoea. Scurr (1954) gives an example, in a six-year-old child, of hypercapnoea simulating cur-

arization, though in this case there was no urgency of respiration or tracheal tug.

Seevers (1944) describes the inhalation of 7–12 per cent carbon dioxide as causing some rise in blood pressure, tachycardia, sweating and hypercapnoea. High concentrations, however, give a depressant effect with a failing respiration (Leake and Waters, 1929). Westlake *et al.* (1955) describe the general effect of high concentrations of carbon dioxide as being "warm sweating extremities, bounding pulse, low blood pressure, hypothermia and some mental clouding or coma."

Neurological effects of carbon dioxide poisoning.

A common sign of carbon dioxide poisoning would appear to be muscular movement (Leake and Waters, 1929; Davies and Mackinnon, 1949; Hickman *et al.*, 1952). Waters (1937) reports that "twitching of the facial muscles is one of the commonest signs of carbon dioxide excess in anaesthesia". On the other hand, Pollock (1949) states that the convulsions induced by Metrazol are depressed by carbon dioxide inhalations.

Hypercapnoea may cause cerebral vasodilatation giving a rise of intracranial pressure (Goldensohn *et al.*, 1951). Case and Haldane (1941), working on conscious volunteers breathing 6 per cent carbon dioxide, describe mental distress, photophobia and slight headache while the carbon dioxide was being inhaled and nausea when the subject left the experimental chamber and breathed air.

Anaesthetic drugs and carbon dioxide excess.

Many drugs commonly used in anaesthesia are stated to be adrenergic, e.g. morphine (Bodo *et al.*, 1937), chloroform (Bathia *et al.*, 1933), ether (Elliott, 1912), trichlorethylene (Johnstone, 1951), and cyclopropane (Allen *et al.*, 1940). Johnstone (1950) has shown that carbon dioxide retention may augment the adrenergic effect of certain anaesthetic gases with the production of ventricular extrasystoles.

Beecher and Todd (1954) surveyed more than half a million anaesthetics and described a six-fold increase in anaesthetic deaths since the introduction of relaxants, and attribute this to some inherent toxicity of these agents which affects the cardiovascular system. Most British anaesthetists would probably not agree with their conclusions but can hardly argue with their facts. As the main untoward effect of relaxant drugs is underventilation, hypercapnoea and suboxygenation may have played a part in this increased mortality as suggested by Pask (1955). Johnstone (1955) has postulated that the use of adrenergic drugs in the presence of carbon dioxide excess would partially explain the raised mortality rate as the increase was more striking in the group where these drugs were used than in the group where a nitrous oxide-pethidine sequence was employed. Stead *et al.* (1953) and Harbord and Lucas (1953) have demonstrated that respiratory acidosis, to quite a high degree, may complicate apnoeic techniques with relaxants. Sims *et al.* (1951), investigating the effect of hypercapnoea and anoxia on the liver, demonstrated that carbon dioxide excess during anaesthesia caused considerable increase in the frequency and severity of hepatic damage with ether and in particular with chloroform.

Hyperventilation.

Excessive artificial ventilation carries its own risks but these are probably not so dangerous as those of hypercapnoea, and hyperventilation is less likely to occur during anaesthesia than hypoventilation, though Dundee (1952) found a rise in pH in manually controlled respiration. Many authors investigating the effects of hyperventilation describe hypotension with, in some cases, loss of consciousness (Seevers *et al.*, 1939; Vincent and Thompson, 1928; Vincent and Cameron, 1915; Dale and Evans, 1922). Kety and Schmidt (1948) describe how mechanical overventilation produced a diminution of cerebral blood flow by 30 per cent which they ascribed as being due to a general vasoconstriction and to a fall in cardiac output; but in mechanical over-ventilation a number of other factors arise, such as the pressure of inspired gases, the inspiration-expiration ratio and the length of inspiration, and the effects they describe may have been due to causes other than alkalosis. Harwood (1938) states that the signs and symptoms of hyperventilation are "dizziness, blurring of vision, numbness and tingling of the extremities" and says that long continued hyperventilation leads to spasms of the muscles of the face, hands and feet, going on to stridor, generalized convulsions and unconsciousness. When this description is compared with that of Waters (1937) it would appear that there is considerable similarity between extreme hypercapnoea and extreme overventilation, though there is not likely to be any confusion during most anaesthetics.

It will be appreciated from the above quotations from the literature that the manifestations of hypercapnoea and respiratory alkalosis are very protean. The clinical signs said to be due to changes of carbon dioxide from the normal are capable of misinterpretation as they can be produced by other causes. Riskin *et al.* (1954) gave examples of hypertension during anaesthesia which were not due to hypercapnoea. Price *et al.* (1953) have shown that a rise in the systolic blood pressure can occur without a rise in the carbon dioxide tension though the mean increase is always greater if respiratory acidosis does exist. Westlake *et al.* (1955) demonstrated that severe hypercapnoea may cause hypotension. It must be borne in mind, however, that many of the effects described are due to extremely high abnormal variations of carbon dioxide tensions and are unlikely to be met with in ordinary anaesthetic practice.

SUMMARY

(1) A simple method of estimating the carbon dioxide content of end-of-expiration air is described.

(2) Figures of the carbon dioxide percentage are given as found during spontaneous, "assisted" and controlled respiration.

(3) The clinical effects of hypercapnoea and hyperventilation are described as gleaned from the literature.

(4) It is suggested that control of respiration during anaesthetic practice may be achieved within a wide range of carbon dioxide tensions unless some means is used to measure the carbon dioxide concentration.

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Brit. J. Anaesth. (1956), **28**, 37

A SIMPLE METHOD OF CARBON DIOXIDE ESTIMATION IN EXPIRED AIR

BY

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A SIMPLE method for the estimation of carbon dioxide in air or gas mixtures containing anaesthetic gases finds many applications in the investigation of anaesthetic problems and in the control of artificial respiration by mechanical respirators. This adaptation of already established techniques utilizes apparatus which may be found in most hospitals. It is rapid, and can be performed at the bedside or in the operating-room.

The principal has been employed for some time (Higgins and Marriott, 1917; Wilson, Orcutt and Peterson, 1932; Wilson, 1933), and has recently been adapted by Brinkman in an instrument known as the "Carbovisor". The gas mixture to be examined is brought into equilibrium with an indicator solution lightly buffered with sodium bicarbonate. The tension of carbon dioxide in the gas mixture determines the pH achieved in the buffered solution and the pH, in turn, determines the colour of the indicator. The colour of the indicator is estimated in a photo-electric colorimeter, using a convenient filter. The indicator solution consists of bromthymol blue 0.005 per cent and sodium bicarbonate 0.05 per cent and it has been found to be stable in storage provided that it is kept in bottles the interior of which have been carefully lined with paraffin wax.

The sample of gas to be analysed is drawn into a syringe with a long needle attached; 10 ml are required. The tip of the needle is then placed underneath the surface of a small quantity of the indicator solution and 2 ml of gas expelled from the syringe; 2 ml of the indicator solution are then drawn in. The syringe is then closed, either with a blanked-off needle hub or by thrusting the point of the needle into a rubber bung. The syringe and

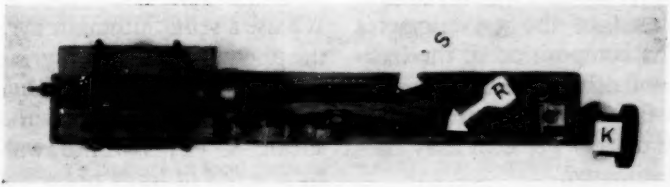

FIG. 1

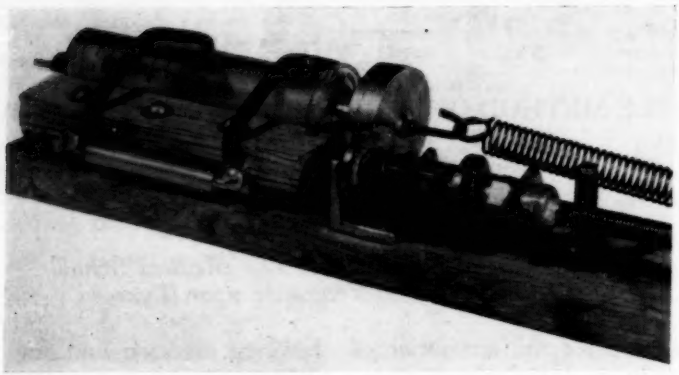

FIG. 2

indicator solution are shaken for one minute. The solution is then transferred to the cuvette of the colorimeter. We have used an "EEL" portable colorimeter employing the small-sized tubes, but no doubt other colorimeters are equally suitable. The red filter No. 205 is employed. Using in the cuvette some indicator solution free of carbon dioxide, the zero point is set to a convenient position on the scale, usually about midway deflection. Calibration is conveniently achieved by having a sample of carbon dioxide in oxygen in a cylinder, which has been carefully analysed. A specimen of indicator is brought into equilibrium with this gas and provides the second point on the calibration line. It has been found by careful check that in these conditions the tension of carbon dioxide in the sample is linearly related to the galvanometer deflection. The composition of the indicator solution and other details mentioned are chosen so that the concentrations of carbon dioxide up to 7 per cent may conveniently be estimated.

It is desirable to check the zero point before each estimation and occasionally to confirm the slope of the calibration line by estimating the standard gas mixture. The indicator solution may change slowly with time but the linearity of its response does not.

The collection of end-expiratory samples.

It is often desirable to collect end-expiratory air when the patient is exhaling through some form of breathing apparatus. Provided that the respiration is slow, satisfactory end-expiratory air may be collected from a polythene catheter passed into the trachea or to some part of the expiratory tube close to the outlet of the natural air passage. The sample withdrawn at the end of exhalation must be small and it is desirable to obtain a mixed sample from several exhalations. We use a semi-automatic syringe shown in the photographs. The syringe is mounted upon a board and the plunger is under tension, tending to be withdrawn by the spring S. This withdrawal is prevented by a series of large brass washers fixed to the rod R which can be rotated by the

knob K. From each of these washers a segment defined by a chord has been cut away so that about two-thirds of the circumference remain. The knob on the plunger of the syringe can escape past this missing segment and the missing segments are fixed upon the operating rod at 180° alternately so that the plunger escapes from one and is immediately caught by the next washer. The respiration is carefully watched and at the end of exhalation the knob K is rotated through 180° thus allowing about 2 ml to be drawn into the syringe. This is repeated until the syringe is full.

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BRAZILIAN CONGRESS, 1955

THE 2nd Brazilian Congress of Anesthesiologists was held in Salvador, Bahia, during the week of November 27 to December 3. Despite the disturbing political situation there was a good attendance of anaesthetists from all parts of this vast country, Rio de Janiero and Sao Paulo being especially strongly represented.

The Congress opened with a cocktail party given by His Excellency the Rector Magnificus of the University, Professor Dr. Edgard Rêgo dos Santos followed by the inaugural session held in the beautiful senate house of the university. A graceful tribute was paid to British anaesthesia when Dr. T. Cecil Gray was invited to preside at this opening. The opening speeches were made by the President of the Executive Committee of the Congress (Dr. Menandro L. de Faria), the President of the Brazilian Society of Anaesthetists (Dr. Zairo Viera), and by the Rector of the University.

The official themes of discussion at the scientific meeting of the Congress were "Pulmonary Ventilation" and "Muscle Relaxants". In addition there was a session devoted to discussion of "Free Subjects".

The programme of social activities gave opportunities for visitors to see many aspects of the culture and folklore of this part of Brazil. Arrangements were made for those attending to see a demonstration of Capoeira, a local form of "boxing", the only rule of which is that the hands must not be used, the blows being struck with the feet and head. This results in an extraordinary exhibition of gymnastic ability, the whole being done to the rhythm of characteristic music provided by a small orchestra of diverse primitive instruments.

The visitors were also taken to a session of *candomblés*, an Afro-Brazilian religious cult with a considerable hold on the negro population of the area, and to watch the age-old method of net fishing in which a net 3½ kilos long is hauled inshore by thirty or more fishermen, again to primitive chants and rhythmic dances originating in far-off Africa. Bahia is so rich in historical buildings, wonderful churches and examples of extremly advanced modern Brazilian architecture that no visitor could have left this Congress without carrying away indelible memories of this fascinating region.

The Congress terminated with a dinner in a *boite* adjoining the Hotel da Bahia, in which the long speeches characteristic of many similar functions in the Anglo-Saxon world were supplanted by songs and dances from various distinguished visitors.

The undoubted success of this 2nd Brazilian Congress, itself testimony of the enthusiasm and enterprise of the Brazilian anaesthetists and their society, was a great tribute to the work of the local organizing committee.

ON CHLOROFORM AND OTHER ANÆSTHETICS

THEIR ACTION AND ADMINISTRATION

BY

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(*Continued from Vol. XXVII, page* 562)

Case 5 is that of a young woman at Hyderabad, who inhaled chloroform to undergo amputation of the middle finger. A drachm was sprinkled on a handkerchief and inhaled. The operator described what occurred as follows: "She coughed a little, and then gave a few convulsive movements. When these subsided, I performed the necessary incisions, which of course did not occupy more than a few seconds. Scarcely a drop of blood escaped." The absence of bleeding seemed to be the circumstance which called the attention of the operator to the state of his patient; and after describing the means which were used without avail to bring about recovery, he continues, "I am inclined to think that death was almost instantaneous; for, after the convulsive movements above described, she never moved or exhibited the smallest sign of life."*

In this case, it is probable that the breathing and the action of the heart were both arrested at the same time, by the action of the chloroform.

Case 6. Charles Desnoyers, aged twenty-two, a patient in the Hôtel-Dieu at Lyons, affected with scrofulous disease of the left wrist, having to undergo transcurrent cauterisation of the joint, inhaled chloroform from an apparatus for five minutes, and died at the beginning of the operation.* Further particulars are not given.

Case 7. A young gentleman, who had returned from Australia to visit his relatives in the neighbourhood of Govan, inhaled chloroform for an intended operation on the great toe, in December 1848. It is stated that the patient, after inhaling it, almost instantly expired. This account appeared in the *Glasgow Herald*, and was copied into the medical journals.† I believe that no further account of the case was ever published.

Case 8 occurred on January 19th, 1849. It is related by Dr. John C. Warren.‡ John Griffith, an Irishman, aged thirty-one, a seaman in the American navy, was admitted into New York Hospital early in December 1848, on his return from Mexico. He was suffering with diarrhoea, chancres, and hæmorrhoids. The following is the account of this accident.

* Lond. Med. Gaz., vol. xlii, p. 84.

* Bouisson, Traité de la Méthode Anesthésique, p. 398.
† London Med. Gaz., vol. xliii, p. 41.
‡ Ibid., p. 712.

" Gurdon Buck, jun., attending surgeon to the New York Hospital, being sworn, says, that ' on or about the 26th of December, I advised that chloroform should be administered to the deceased, for the purpose of examining the condition of the rectum, the parts being in such a state of excessive irritation as scarcely to admit of a separation of the nates. The patient recovered from the effects of the chloroform, and remained in all respects in the same condition, except the local ailments spoken of; and he having never complained of either his head or his chest, and not having suffered from the first administration of chloroform, I directed it to be administered to him for the purpose of performing an operation upon the rectum, and the operation of circumcision to remove a phymosis caused by the chancres: the patient soon became excited by the chloroform, as is usually the case, but not beyond a degree that I have often observed. Shortly after, he became more tranquil: the deceased was placed upon his side, and the operation performed, which consisted in the removal of two external tumours, and the tying of one internal tumour.

" ' At this moment my attention was arrested by my assistant's calling for a wet cloth: on examining the patient, I found his face and neck of a livid leaden hue or colour, the eyes turned upward, the pulse imperceptible at the wrist, and the whole body relaxed; after two or three gasps, he ceased to breathe. Every means was promptly used to restore the deceased, but without effect. The chloroform was obtained from Kent's, 91, John Street, and not exceeding three drachms was administered on a napkin. A portion of chloroform from the same phial had been administered the day before to a patient without any unfavourable effects. About ten minutes elapsed from the commencement of its administration before death took place. On making a post-mortem examination, twenty-four hours after death, I found the face less livid than before death; on examining the head, the brain and its membranes presented no other appearances than are seen in persons dying when in full health; the lungs were a good deal congested, and discharged, when cut, a large quantity of bloody serum; the heart was large, its ventricles and auricles were empty, its condition flabby, the substance of the left ventricle rather softer than natural; about half an ounce of watery fluid was found in the pericardium; the viscera of the abdomen were healthy.' "

This case differs from those previously related in respect to the time at which the fatal occurrence took place. It was not till ten minutes from the commencement of inhalation, and when an operation which probably occupied two or three minutes had been performed, that the patient suddenly expired. The evidence of paralysis of the heart, is however, distinct enough in the absence of pulse at the wrist, and the livid hue of the countenance. In several of the previous cases, there was sudden pallor at the moment when the heart ceased to inject blood into the capillaries, but in a patient well supplied with blood, the sudden arrest of the action of the heart would cause turgescence of the veins and venous capillaries, which would be evident in the face in a few seconds. The syncope occasioned by paralysis of the heart differs from that kind of

syncope which is caused by loss of blood, inasmuch as the right cavities of the heart are full in the former instance, and empty in the latter.

The circumstance of the patient having inhaled chloroform to insensibility three weeks previously, without accident or ill effects, is worthy of notice, as showing that the fatal event did not depend on any peculiarity of constitution.

Although the heart was found to be empty, its flabby condition and the watery fluid in the pericardium indicate that it must have contained blood at the time of death.

Case 9 occurred on January 24th, 1849, at the Hôtel-Dieu, Lyons, where Case 6 previously happened. The patient was a youth, aged seventeen, named J. Verrier, who had been employed as a miner. He was of good constitution, and was about to undergo amputation of the middle finger for necrosis of the first phalanx. The following is the account of the accident.

"As the patient's health was good, he was at once, and by his free consent, placed under the influence of chloroform. As usual, a piece of fine gauze was employed; it was spread over the face, leaving a free passage for atmospheric air; the chloroform was dropped from time to time upon that portion of the gauze which was over the nostrils. It was administered by two assistants who were accustomed to its use, and who at the time attended to the pulse. The operator superintended the assistants. At the end of four or five minutes, the patient still felt and spoke; and at the end of another minute, he still spoke and was somewhat restless. Up to this time, from a drachm to a drachm and a half of chloroform had been employed. The pulse was regular, and of the normal strength. All at once the patient raised his body, and struggled so that the limbs escaped from the hold of the assistants, who however seized them quickly, and replaced the patient in his position. Within a quarter of a minute, one of the assistants stated that the pulse at the wrist had ceased to beat. The handkerchief was removed. The countenance was completely altered. The action of the heart had altogether ceased; the pulse could not be felt anywhere; and the sounds over the region of the heart could no longer be heard. Respiration still continued, but it became irregular, weak, and slow; and at length ceased completely in the space of about half a minute.

"The extreme danger of the patient was manifest, and immediate and energetic means were employed to rouse him. Ammonia was held to the nostrils, and rubbed in large quantity over the surface of the chest and abdomen. It was also applied to the most delicate parts of the skin, *e.g.*, the lips and the extremity of the penis, with a view to excite irritation. Mustard was used; the head was inclined over the bed; and, finally, an attempt was made to restore respiration by means of alternate pressure on the abdomen and chest. After two or three minutes, respiration reappeared, and even acquired a certain fulness, but the pulse nowhere returned. Frictions were continued. Respiration became again slower, and at length ceased. Artificial inflation was practised, at first through the mouth, and afterwards through the larynx, by passing a tube through the glottis, and it was perceived that air had passed from the mouth into the stomach. The precordial,

epigastric, and laryngeal regions were energetically cauterised with a hot iron. The pulse did not return. For a space of half an hour every effort was made to resuscitate the patient; but in vain.

"The autopsy could not be made until seventy-two hours after death. The temperature being low, the body showed no signs of decomposition; there was still rigidity of the limbs. The features were not altered. The examination of all the organs was made with care.

"The stomach contained about one ounce and a half of a thick fluid, of the colour of the lees of wine, in no respect resembling an alimentary fluid. The organ was distended with gas, as was also the rest of the alimentary canal, which was otherwise sound. The liver and spleen were somewhat congested.

"The heart, which was normal in volume, was flaccid and empty, contained neither blood nor air. The ventricular parietes were moistened by a fine, very red foam, as if from the presence of a little blood, which had been, as it were, whipped by the fleshy columns of the heart. The venæ cavæ and the portal veins were distended by black fluid blood in great quantity. On the Eustachian valve there was a fibrinous clot, moderately firm, and weighing from sixty to seventy grains. It was the only clot met with in the cavities of the heart and great vessels. These cavities, which were carefully opened, did not contain any appreciable quantity of air.

"The lungs retracted on opening the chest. They presented both in their surface and in their substance a very black colour; otherwise their tissue was healthy. The larynx and trachea presented no lesion. The brain was normal. The sinuses of the dura mater contained a considerable quantity of black uncoagulated blood."*

In this case every precaution appears to have been taken, except that which is the most essential, of regulating the amount of vapour in the respired air. Arrangement was made that there should be amply sufficient air for the purpose of respiration; the patient was carefully watched by three persons at least, one of whom was constantly attending to the pulse, but with no other result than to be able to announce the exact moment when it suddenly stopped. The arrest of the action of the heart in this case took place at a time when the patient was not yet rendered insensible by the chloroform, although he had been inhaling it for five minutes. We must conclude that during these five minutes the vapour he inhaled was largely diluted with air, and that he then inhaled vapour in a much less diluted form. It is not improbable that he took a deep inspiration of strong vapour, just at the moment when he struggled violently, and within a quarter of a minute of the time when his pulse suddenly ceased.

The breathing continued a little time after the heart ceased to beat, and it is therefore very probable that, if this organ had not been irrecoverably paralysed, the natural breathing would have restored its action after a short pause, that would have attracted but a momentary attention. As the spontaneous breathing of the patient did not restore the heart's action, there is no ground for surprise that the measures adopted did not succeed.

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* Ibid., p. 747, from l'Union Médicale.

Case 10 was that of a labourer, named Samuel Bennett. It occurred on February 20th, 1849, at a dispensary in Westminster. The patient inhaled chloroform for amputation of one of the toes. Half an ounce of chloroform was "sprinkled on a handkerchief, and held over the mouth and nose. . . . This quantity of the agent failed, however, to produce anæsthesia, having caused only the ordinary excitement and struggling." After a delay of two hours, more chloroform was procured, and half an ounce was again applied on a handkerchief, "care being taken to allow the entrance of air at short intervals." Insensibility was induced, and the toe was amputated; the chloroform being applied, as I was told, during part of the time of the operation. At the close of the operation, no blood escaped when the pressure was removed from the arteries; the patient was in fact dying, and in a short time expired. "A few inspirations were noticed after the pulse had ceased at the wrist."*

The lungs were of a dark venous hue throughout, a large quantity of blood escaping from them when cut into. Mucous membrane of trachea and bronchi congested. Heart rather large but flabby; auricles empty; each ventricle contained about an ounce of semi-fluid blood (the lungs had been inflated). Head: sinuses and veins contained blood, but not to any remarkable amount. But few bloody points occurred in cutting into the cerebral mass. Kidneys congested.

The failure of the first attempt to cause insensibility in this case, when so large a quantity of chloroform was used, illustrates very forcibly the uncertainty and irregularity of the way in which it was administered. On the first occasion only excitement and struggling were produced, and on the next the patient died suddenly.

Case 11 occurred on August 23rd, 1849, at Langres, France. The subject of it, Madame Labrune, was reported to be a healthy married woman. She inhaled chloroform with the intention of having a tooth extracted. "Complete insensibility was not produced at the first trial: more chloroform was placed on the handkerchief, and she drew a full inspiration. Her countenance immediately became pallid; her features were visibly altered; there was dilatation of the pupils with a convulsive rolling of the eyes; and no pulse could be felt. Every attempt was made to restore life, but without success. She died as if struck by lightning."† The instantaneous arrest of the circulation, on a full inspiration being taken, immediately after more chloroform had been placed on the handkerchief, is particularly worthy of notice. The heart was paralysed, in this instance, as quickly as in experiment No. 25, above related.

No inspection of the body is reported in this case.

Case 12 is the first which occurred in any of the hospitals in this metropolis. The following is the account of it.

"John Shorter, aged forty-eight, a porter, known to Mr. Solly for some time as a very active messenger, habits intemperate, but apparently in perfect health, was admitted into George's ward, under

* Lancet, 1849, vol. i, p. 205.

† L'Union Médicale, Sept. 8th, 1849; and Med. Gaz., vol. xliv, p. 478.

Mr. Solly, on the 9th October, 1849, suffering from onychia of the left great toe, which had existed some time. It was determined to remove the nail, the man having decided before entering hospital on taking chloroform.

"On Wednesday, October 10th, at a quarter to two P.M., he began to inhale the chloroform with one drachm in the inhaler. It had no visible effect for about two minutes; it then excited him, and the instrument was removed from the mouth, and about ten drops more were added; he then almost immediately became insensible; the chloroform was taken away, and the nail removed. He continued insensible; and, his face becoming dark, the pulse small, quick, but regular, respiration laborious his neckerchief was removed, and the chest exposed to fresh air from a window near to the bed; cold water was dashed in his face, the chest rubbed, and ammonia applied to the nose. After struggling for about a minute, he became still, the skin cold, pulse scarcely perceptible, and soon ceased to be felt at the wrist; respiration became slow and at intervals, but continued a few seconds after the cessation of the pulse. Immediately on the appearance of these symptoms, artificial respiration was commenced by depressing the ribs with the hands and then allowing them to rise again until the proper apparatus was brought, when respiration was kept up by means of the trachea tube and bellows, and oxygen gas introduced into the lungs by the same means. Galvanism was also applied through the heart and diaphragm, but all signs of life ceased about six or seven minutes after the commencement of inhalation. These means were persisted in until a quarter past three, but to no purpose. On removing the inhaler, the sponge, which only contains one drachm, fell upon the floor, and the chloroform splashed about,—thus showing that a considerable part of the chloroform remained unused; so that the patient could not have inhaled more than a drachm. Every endeavour was made to procure a post-mortem examination, but in vain."*

* Lond. Med. Gaz., vol. xliv, p. 757.

(*To be continued*)

EDITORIAL ANNOUNCEMENT

It is recognized that the subscription of £3 15s. per annum for the *British Journal of Anaesthesia* might be a heavy burden for anaesthetists in trainee positions, despite the fact that for this subscription they receive twelve monthly issues, including two of special educational interest. Because of our desire to interest aspirants to the specialty in this publication, the publishers have agreed to supply the Journal to *bona fide* trainees in Great Britain, on application for three years at the reduced rate of £2 10s.

Forms of application for this concession may be had on request to the Editors.

STIMULATION OF THE ULNAR NERVE IN MAN

Sir,—We were most interested in the excellent account which Dr. Brown gave of his careful experiments, on the effects of anaesthetics on the response to stimulation of the ulnar nerve in man, which appeared in the October issue of this journal.

We think that we can offer a plausible explanation of the apparent contradiction between the general clinical observation that ether potentiates the action of d-tubocurarine and his failure to find any clear experimental evidence of neuromuscular blockade with nitrous oxide/ether anaesthesia.

We have recently (1955a, b) determined the dose-effect curve for the relaxant action of gallamine triethiodide, a curare-like relaxant, in a human volunteer. This was of normal sigmoid form (see fig. 1).

We know virtually nothing of the dose-effect curve for the neuromuscular blocking action of ether. Let it be assumed to be of substantially the same form as that for gallamine (when plotted in terms of degree of relaxation against blood concentration). Assume also that when ether and curare-like relaxants are administered together their neuromuscular blocking effects are simply additive, which seems reasonable since Normann and Löfström (1954) have shown that the effects of ether and d-tubocurarine on ganglionic transmission in the cat are simply additive.

Probably 5 per cent relaxation, according to the definition we gave (1955a) of "degree of relaxation", would be the least which could be reliably detected by Dr. Brown's method. He found little more than a suggestion of neuromuscular blocking action due to deep ether anaesthesia (the plane 4 he referred to). Thus the blood concentration

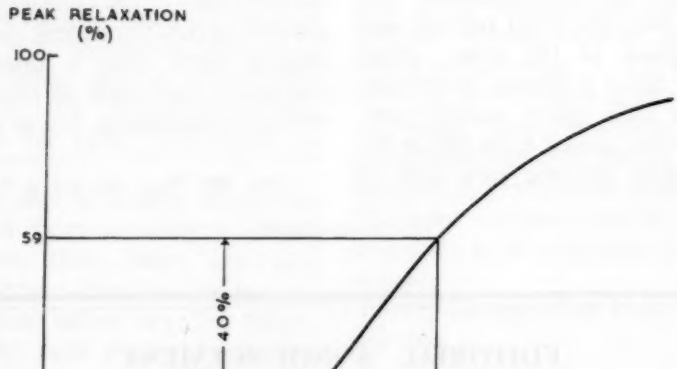

FIG. 1
Dose-effect curve for intravenous injection of gallamine triethiodide in a 70-kg man.

of ether required to produce deep anaesthesia probably produces, say, 1 per cent relaxation. This degree of relaxation is that produced by a dose of 0.16 mg/kg of gallamine (see fig. 1).

Now suppose that to a deeply etherized patient a dose of 0.28 mg/kg of gallamine is given. He has already received the equivalent of 0.16 mg/kg of gallamine and therefore the effect will be that of $0.28+0.16=0.44$ mg/kg namely 59 per cent relaxation. Had this dose of gallamine been given in the absence of ether the relaxation would have been only 19 per cent. Thus the presence of the ether increased the relaxant effect of the gallamine by 40 per cent. This increase, we feel, would be clearly detectable clinically as a potentiation.

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FIFTH ARGENTINE CONGRESS OF ANAESTHESIA

THE effects of recent political developments in Argentina were obvious throughout all the meetings of this Congress which was held in Buenos Aires from October 22 to October 29, 1955. The spirit of the people was typified by the sole toast of "Liberty" which Dr. Roberto Owen Elder, chairman of the congress, proposed at the opening banquet. In the closing address Dr. Julio F. Parada (Chairman of Asociacion Argentina de Anestesiologia) remarked that, although this was the fifth such meeting to be held in the country, it was their first free Congress of Anaesthesia.

Symposia were held on "Anaesthesia and the Autonomic Nervous System" and "Resuscitation", a panel of speakers dealing with various aspects of these subjects. Following each of these was a round-table discussion at which the members of the panel answered questions submitted by the audience.

The visiting speakers included Drs. John J. Bonica (United States), John W. Dundee (Great Britain) and Eduardo Escalona Sylvester (Chile). Dr. Bonica's topics were the therapeutic use of nerve blocks with special reference to the relief of pain, and endobronchial anaesthesia. Dr. Dundee dealt with various aspects of the pharmacology and clinical use of the thiobarbiturates and with the use of hypothermia in neurosurgery, while Dr. Sylvester discussed Chilean experiences with potentiated anaesthesia and "artificial hibernation". Opinions were divided as to the benefits of these techniques, but they were generally considered to be unduly cumbersome for routine use. Since the scientific meetings were all held in the afternoons and evenings, an opportunity was afforded to see these, and other workers, give clinical demonstrations in the mornings.

Among the other topics of discussion, much interest was shown in the clinical use of Arfonad, and intravenous procaine. The popularity of the latter technique is largely due to the shortage of nitrous oxide in Argentina, and the combined experience of the various speakers must total many tens of thousands of cases.

The proceedings of the Congress are to be published separately at a later date and these should afford readers an opportunity to learn of the many advances that have been made in Argentinian anaesthesia during the last decade.

GLASGOW AND WEST OF SCOTLAND SOCIETY OF ANAESTHETISTS

THE Society held its first meeting of the 1955–56 session in Glasgow on October 29, 1955. This meeting was the annual joint meeting with the Association of Anaesthetists of Edinburgh. The speaker was Mr. J. Schorstein, Neurosurgeon to the West of Scotland Neurosurgical Unit, Killearn, his subject being

"INVESTIGATIONS OF CONSCIOUSNESS"

Two words are derived from the Latin *conscientia*: conscience and consciousness. Conscience is the older concept and consciousness appears first in Descartes' system as a neutral awareness of man of himself, whilst conscience was moral and religious self-knowledge. More recently consciousness has come to mean simply wakefulness and responsiveness without any distinctive human values so that man's consciousness may now be investigated in animals. These changes in meaning must reflect historical changes in man's self-estimation.

During the end of the last and the beginning of the present century evidence from brain wounds and later from brain surgery began to discredit Hughlings Jackson's and Gower's belief that the cortex of the hemispheres played an essential part in maintaining consciousness. Until the 1930s the activity of the brain could only be inferred from observable behaviour, but with the advent of electro-encephalography more direct evidence became available, for the shape and frequency of cortical potentials could broadly be correlated with states of wakefulness and sleep. The transition from sleep to waking is characteristically associated with an acceleration in the electro-encephalographic record and an identical change can be brought about by stimulation of medial brainstem structures which have become known collectively as the ascending reticular formation. Lesions of the reticular formation, but not of the classical sensory pathways which lie more laterally, produce both stupor and a slowing of the electro-encephalographic record. It seems likely that the classical sensory pathways send collaterals to the reticular formation which relays impulses to wide areas of both cerebral hemispheres and it may be that the reticular formation alters the quality of selected sensory impulses in such a manner that they can arouse the sleeping cortex and maintain it in its waking state. Some anaesthetics may have a specific depressing influence on the multineural chain of the reticular formation.

The results of these animal experiments are not easily translated into explanations of clinical states where the underlying lesion is rarely both stationary and unassociated with abnormalities in other parts of the central nervous system, but in some instances the correlation between brainstem damage and changes in responsiveness has been known for a long time. The unconsciousness which occurs in the advanced stages of supratentorial pressure is due to herniation of medial temporal convolutions through the hiatus tentorii and subsequent interference with blood supply to the brainstem, and prolonged stupor following head injuries frequently has a similar pathology. Studies of encephalitis and deficiency encephalopathies provided the first clinicopathological evidence pointing to the importance of that region maintaining consciousness, and more recent reports suggest that brainstem lesions may be responsible for the prolonged and irreversible stupor which follows severe cerebral anoxaemia. Other examples are provided by tumours of the brainstem and hypothalamus and by operative damage and it is probably true to say that the hazards of neurosurgical anaesthesia and operations are largely those affecting the multineuronal chain of the reticular system.

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